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Hardwood Management Problems in Northeastern British Columbia: An Information Review

by:

E.B. Peterson[1], R.D. Kabzems[2], and N.M. Peterson

[1] Western Ecological Services Ltd., Victoria, B.C.

[2] Consultant, Dawson Creek, B.C.

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Forestry Canada
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5
(604) 388-0600

or

B.C. Ministry of Forests
Research Branch
31 Bastion Square
Victoria, B.C. V8W 3E7
(604) 387-6719

EXECUTIVE SUMMARY

In 1986, a task force within the B.C. Ministry of Forests recommended interim strategies for managing hardwoods in the Fort Nelson, Fort St. John, and Dawson Creek timber supply areas. In decreasing order of importance, the hardwood species involved are aspen, balsam poplar, birch, and black cottonwood. A working group that met at the Boreal Hardwood Research and Development Meeting in Prince George in 1987 identified 12 problems associated with boreal hardwood use and management:

High priority problems

Outdated inventory
Land use conflict.

Medium priority problems

Lack of awareness of hardwood use and management opportunities
Hardwood stocking standards
Stand tending requirements
Growth projections.

Medium to low priority problems

Reforestation requirements for pure aspen and mixedwood types.

Low priority problems

Slash disposal
Regeneration response
Compaction of soils
Erosion
Gene conservation.

The present literature review, conducted in early 1988, addressed these 12 problems, focussing almost exclusively on aspen. Each problem is reviewed with a brief statement of the circumstances behind it, a synopsis of related information from the literature, interim solutions based on available information, and suggested follow-up work.

The two highest priority questions (outdated hardwood inventory and uncertainties about land-use choices) were aided the least by information from the literature. These are subjects that must be addressed directly by regional data collection programs and by regional decision-making where land-use choices are required. Such efforts are under way.

Two of the medium priority problems (hardwood stocking standards and growth projections) were also poorly served by the literature review. The reason is the same as for the topics of hardwood inventory and land use, namely that there is no substitute for direct data collection and decision-making in the region. For five subjects (hardwood use, stand-tending requirements, reforestation requirements, slash disposal, and regeneration response) information is abundant in the literature. Much of this information is considered to be ecologically applicable to hardwood and mixedwood ecosystems in northeastern British Columbia.

Compaction of soils and erosion are problems for which the literature contained relatively little information from study sites dominated by boreal hardwoods. There is little evidence that erosion is a distinctly different problem in hardwood-dominated ecosystems than in mixedwood or coniferous ecosystems. Compaction is potentially of more concern in hardwood sites because the equipment that causes compaction may also damage root systems on which boreal hardwoods depend for regeneration. Existing knowledge, derived from a variety of forest types, of how to reduce soil compaction and erosion, is also considered to be applicable to hardwood or mixedwood types in northeastern British Columbia.

The first opportunity to incorporate gene conservation and genetic considerations into boreal hardwood silviculture will likely arise in the context of encouraging clones that possess superior growth

rates or other desirable characteristics. Considerable information exists on clonal variation in natural aspen stands, but this information is not expected to be applied in the near future. Ways to use the existing hardwood inventory will be the focus before concerted efforts are made to manage the best clones.

ACKNOWLEDGEMENTS

We thank the Research Branch, Ministry of Forests, for financial support to prepare this review. The report benefitted greatly from review of an earlier draft by Phil Comeau, Ministry of Forests, Victoria, and Les Herring, Ministry of Forests, Prince George.

Most of the review is based on widely available published documents, but important unpublished information was also provided by Frank Hegyi, Ministry of Forests, Victoria, and Sherry Hambly, Ontario Ministry of Natural Resources, Toronto. Personal communications are cited in the report. We are grateful for advice provided in these communications by: W.J. Ball, Canadian Forestry Service, Winnipeg; P. Comeau, Ministry of Forests, Victoria; C. DeLong, Ministry of Forests, Prince George; N. Denney, Pelican Spruce Mills Ltd., Edson; C. Dermott, Alberta Forest Service, Edmonton; J. Fochler, Alberta Forest Service, Spruce Grove; J. Gray, Ministry of Forests, Fort St. John; F. Hegyi, Ministry of Forests, Victoria; L. Herring, Ministry of Forests, Prince George; W. Ives, Canadian Forestry Service, Edmonton; D. MacLennan, Ministry of Forests, Dawson Creek; M. Nock, Ministry of Forests, Fort St.John; J. Revel, Ministry of Forests, Prince George; C. Smith, Alberta Forest Service, Edmonton; and C. Wilson, Ministry of Forests, Dawson Creek.

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1 INTRODUCTION

This review was initiated by the British Columbia Ministry of Forests as a result of several previous initiatives by ministry personnel, mainly in the Prince George Forest Region. The first was a discussion paper that reviewed the effect of hardwoods on silviculture in that region[1]. Its focus on methods for harvesting and treating boreal mixedwood stands to promote coniferous regeneration was based on two assumptions prevalent in 1983:

1) conifers were considered to be more desirable than hardwoods; and

2) because the initial natural succession to hardwoods after fires automatically ensures an inventory of hardwoods, it was felt that regeneration efforts should focus on conifers.

The consensus was that, without a concerted effort to promote conifers, many of the sites best suited to coniferous stands of high productivity would be lost.

The second initiative was a review undertaken in response to new interests in the commercial use of northeastern British Columbia's hardwood resource. The review resulted in a May 1986 task force report entitled *Interim Strategies for the Management of Hardwoods in the Boreal Biogeoclimatic Zone of the Prince George Forest Region* (Revel *et al.* 1986). It is the most frequently cited reference in the present report, whose goal was to complement the boreal hardwood information already assembled by specialists familiar with field conditions and hardwood management problems in northeastern British Columbia.

The third initiative was by a working group (Appendix 1), whose deliberations are recorded in the minutes of the *Boreal Hardwood Research and Development Meeting* held in Prince George on 22 October 1987. That meeting resulted in the identification of the following 12 problems related to boreal hardwoods:

High priority:
- Outdated inventory
- Land use

Medium priority:
- Lack of awareness of hardwood use and management opportunities
- Hardwood stocking standards
- Stand tending requirements
- Growth projections

Medium to low priority:
- Reforestation requirements for pure aspen and mixedwood types

Low priority:
- Slash disposal
- Regeneration response
- Compaction of soils
- Erosion
- Gene conservation

There was also a decision to screen the aspen-related literature to search for interim solutions to the 12 identified problems. To meet this objective, the Research Branch of the Ministry of Forests issued a contract to Western Ecological Services Ltd., Victoria. The rationale behind the literature review was that,

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1 Revel, J. 1983. The impact of some hardwoods on silviculture in the Prince George Forest Region. B.C. Min. For., Prince George. Unpubl. discussion paper. 16p.

in the short term, boreal hardwood management practices could be based on experience from other regions in North America. It was recognized, however, that this interim measure would not be a substitute for development of local management practices specific to British Columbia's boreal hardwood ecosystems.

2 BRITISH COLUMBIA'S BOREAL HARDWOOD RESOURCE

In northeastern British Columbia, the term "hardwoods" can refer to aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera* ssp. *balsamifera*), black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), or birches (*Betula* spp). In this report, however, unless specified otherwise, it refers mainly to aspen and balsam poplar, the two dominant hardwood species in the Peace and Fort Nelson Timber Supply Areas (TSA's).

The proportions of net volumes represented by softwoods and hardwoods in these TSA's, and the relative proportions of the key species within the hardwood component, are listed in Table 1. The 36.9% of total timber supply in the form of hardwoods is made up of 74.1% aspen, 13.1% balsam poplar, and 12.8% birch in the Fort Nelson TSA; in the Peace TSA, 21.5% of the total timber supply is hardwoods, consisting of 81.2% aspen, 15.5% balsam poplar, and 3.2% birch. By comparison, in Alberta's Volume Sampling Region 7 (Uplands Foothills) which is adjacent to the southeastern corner of the Dawson Creek TSA, aspen makes up 75.3% of the hardwood volume, compared to 18.0% for balsam poplar and 6.7% for birch (C. Dermott, pers. comm., Alta. For. Serv., Edmonton, Alta. 1988). Although birch makes up a significant portion of the hardwood net volume in the Fort Nelson TSA, this species was excluded from the present review because it is not presently planned for use in panelboard or pulp operations.

TABLE 1 Relative proportions of softwood and hardwood net volumes, and relative proportions of species volumes within the hardwood component, for the Fort Nelson and Peace Timber Supply Areas[a]. (Source: Inventory Branch, Ministry of Forests, pers. comm., March 1988.)

	Area of forest in mature type (million ha)	Net volume[b] in mature type (million m^3) (%)		Make-up of hardwood net vol. in mature type (million m^3) (% hardwood total)			
		Softwood	Hardwood	Aspen vol.(%)	Balsam poplar vol.(%)	Black cottonwood[c] vol.(%)	Birch vol.(%)
Fort Nelson TSA	1.692	18.86(63.1)	11.02(36.9)	8.17(74.1)	1.44(13.1)	- (0)	1.41(12.8)
Peace TSA	2.117	29.76(78.5)	8.16(21.5)	6.63(81.2)	1.27(15.5)	- (0)	0.26(3.2)

a Separate volume estimates are not yet available for the recently redefined Fort St. John and Dawson Creek Timber Supply Areas; estimates for these two areas are combined under the area formerly known as the Peace Timber Supply Area.

b Net volumes are for trees with dbh of 17.5 cm or greater, to a 10 cm top diameter, for all ownership codes combined.

c Inventory branch data record only "cottonwood" without distinguishing between balsam poplar and black cottonwood. Because of the geographic location of these TSA's, all of the "cottonwood" net volume can be assumed to be balsam poplar.

The geographic boundaries between balsam poplar and black cottonwood in northeastern British Columbia are not uniformly recorded in the literature. Krajina *et al.* (1982) mapped the approximate boundary along a line that extends east from the town of Mackenzie to the Sukunka River valley and then

southeastward to the headwaters of the Parsnip River. Black cottonwood predominates southwest of this boundary and balsam poplar northeast of it. Although some published distribution maps do not show black cottonwood east of the Rocky Mountains in northeastern British Columbia, Manning (1975) mapped the species as far east as the British Columbia-Alberta border and as far north as the Peace River in British Columbia. Brayshaw (1965) described black cottonwood along the Red Deer and other rivers in southwestern Alberta, and one of the authors of this report has observed poplars with three-valved capsules, a feature that distinguishes black cottonwood from the usual two-valved capsules of balsam poplar, as far east as Lesser Slave Lake in Alberta. From these observations, one would expect hybrids between black cottonwood and balsam poplar to occur at many locations within the Dawson Creek, Fort St. John, and Fort Nelson TSA's. However, for this report, the boundary between the two species shown in Figure 28 of Krajina *et al.* (1982) was considered to be the best information available. Thus, except for a small portion of the Dawson Creek TSA between the Parsnip and Sukunka rivers, balsam poplar would be expected to be more prevalent than black cottonwood in northeastern British Columbia.

TABLE 2. Relative proportions of coniferous and *Populus* biomass, by province, in main poplar area of Canada. (Source: Bonnor 1985.)

	Biomass (millions of ovendry tonnes) on forest land that by law or policy is available for harvesting of forest crops				
	Coniferous	% Total	Populus[a]	% Total	Total
Yukon	149	92.0	13	8.0	162
British Columbia	**8713**	**93.6**	**592**	**6.4**	**9305**
Alberta	1529	73.5	551	26.5	2080
Saskatchewan	789	82.2	170	17.8	959
Manitoba	793	75.9	252	24.1	1045
Ontario	2818	81.8	628	18.2	3446
Quebec	3230	95.1	166	4.9	3396

[a] In British Columbia and Yukon, this category would include aspen, balsam poplar, and black cottonwood. In the other listed provinces it would include aspen and balsam poplar.

British Columbia's coniferous biomass is so dominant on both a provincial and national scale that the hardwood component of the province's forest resource has received little attention (Manning 1975). The same is true in most parts of Canada (Morley 1986). In the zone in which aspen and poplars make up the highest proportion of Canada's total forest biomass, the relative proportions of coniferous and *Populus* biomass, on lands that are available for harvesting of forest crops, show considerable variation from one province to the next (Table 2). In decreasing order, the provinces with the highest proportion of the forest resource represented by hardwoods are Alberta, Ontario, Manitoba, and Saskatchewan. British Columbia's relatively low proportion of hardwoods (6.4%) is offset by the fact that, except for an area in southwestern Ontario, British Columbia contains most of Canada's forest lands capable of supporting more than 100 t/ha (dry weight) of hardwood forest biomass (Bonnor 1985). Although many of these highly productive hardwood sites are in valleys of coastal British Columbia, the large area mapped by Bonnor (1985) within the Dawson Creek TSA, in which average dry weight of hardwood biomass exceeds 100 t/ha, stands out not only provincially, but also on nationally.

3 METHODS

This project was conducted through a literature review and a limited number of interviews with personnel from the Ministry of Forests. The sections below outline the information sources, the criteria used to assess the applicability of information to hardwood or mixedwood ecosystems in northeastern British Columbia, and the format used for a dBase III Plus database of references. The database on file with the Research Branch, Ministry of Forests (Victoria), includes the references cited in this report as well as those that are part of the overall knowledge base for boreal hardwood species, with emphasis on aspen. The literature search for this review ended in April 1988. Reports containing relevant information that have become available within the Ministry since then (e.g. Utzig and Walmsley 1988, Lewis 1988[2], and Lousier 1988[3], are acknowledged in Section 13 though they were not consulted for this review.

3.1 Information Sources

The main source of information was a comprehensive collection of aspen-related literature previously assembled by Western Ecological Services Ltd. as a result of several years of aspen research, conducted on behalf of the Northern Forestry Centre, Forestry Canada, Edmonton. This collection of information is part of a continuing project to prepare a detailed monograph on the ecology, management, and use of aspen and balsam poplar in the prairie provinces, scheduled for publication in 1989-90.

Although many references are cited in this report, key references that contain ecological, silvicultural, and use information relevant to the problems identified for British Columbia's boreal hardwood stands are singled out in Table 3. Any agency or industry involved with aspen management should consider assembling these key references as a basic reference library. The excellent silvicultural guide for aspen in Ontario (Heeney *et al.* 1980) will soon be available in revised form (Davison *et al.* 1988). The forthcoming proceedings of the October 1985 meeting of the Poplar Council of Canada will be another important synthesis of information on management and use of aspen (Morley 1986). In addition to the key references identified in Table 3 are the following bibliographies, which focus either on *Populus* generally or aspen specifically: Farmer and McKnight (1967); Lamb (1967); Pronin and Vaughan (1968); Shoup *et al.* (1968); Commonwealth Bureau of Soils (1971); Hart (1976); Hambly (1985).

Other important information sources are several unpublished documents, identified by Ministry of Forests personnel. These include the minutes of the Boreal Hardwood Research and Development Meeting. A computer search of aspen-related references in the Weyerhaeuser database, commissioned by M. Carlson of Kalamalka Research Station, was also consulted; and Ms. E.S.L. Hambly of the Ontario Ministry of Natural Resources made her 1985 aspen literature review available before its publication in the forthcoming proceedings of the 7th Annual Meeting of the Poplar Council of Canada.

3.2 Criteria for Applicability of Information to Hardwood Forests of Northeastern British Columbia

Most of the information relevant to boreal hardwood management comes from study sites outside northeastern British Columbia. Criteria were therefore needed by which to judge the applicability of the information to that part of British Columbia.

The first criterion centred on tree species. Aspen information was given the highest priority because aspen is the dominant boreal hardwood species. Information on balsam poplar and black cottonwood was given second and third priority, respectively. Information on white birch was not reviewed (even though the species occurs in small volumes in northeastern British Columbia [Table 1]), nor was the

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2 Lewis, T. 1988. Guidelines for timber harvesting prescriptions for interior sites of various degradation sensitivities. B. C. Min. For., Research Branch, Victoria, B. C. Author's draft.

3 J.D. Lousier. 1988. Impacts of forest harvesting and renewal on soil properties and site productivity. B. C. Min. For., Research Branch, Victoria, B. C. Author's draft.

TABLE 3. References relevant to hardwood management problems in Northeastern British Columbia

Title	Authors	Available from:
Utilization of hardwoods in northern Alberta. Main report and summary report	Woodbridge, Reed and Associates Ltd. (1985)	Northern Alberta Development Council 9621 - 96 Ave., Postal Bag 900-14, Peace River, Alberta T0H 2X0
Aspen quality workshop, February 12, 1987	Forestry Canada and Alberta Forest Service (1987)	Regional Development Forestry Canada, 5320 - 122 Street, Edmonton, Alberta T6H 3S5
Management and utilization of northern mixedwoods	Samoil (1988)	As above
Utilization and marketing opportunities for Alberta aspen	Wengert (1988)	As above
Proceedings of the workshop on aspen pulp, paper and chemicals	Wong & Szabo (1987)	As above
Growth and utilization of poplars in Canada	Maini and Cayford (1968)	Information Directorate, Forestry Canada, Ottawa, Ontario K1A 1G5
Poplar utilization symposium	Neilson and McBride (1974)	As above
Trembling aspen in Manitoba	Department of Forestry and Rural Development (1967)	As above
Utilization of western hardwoods	McIntosh and Carroll (1980)	Forintek Canada Corp. Western Forest Products Laboratory, Vancouver, B.C.
Present and future uses of Canadian poplars in fibre and wood products	Keays *et al.* (1974)	Information Directorate, Forestry Canada, Ottawa, Ontario K1A 1G5
Ecology of the aspen parkland	Bird (1961)	Agriculture Canada, Research Branch, Ottawa, Ontario K1A 0C5
A silvicultural guide to the aspen working group in Ontario	Heeney *et al.* (1980) (revised version by Davison *et al.* available Nov. 1988)	Ontario Ministry of Natural Resources Public Information Centre Room 1640, 99 Wellesley St. West Toronto, Ontario M7A 1W3
Boreal mixedwood symposium	Whitney and McClain (1981)	Great Lakes Forest Research Centre, P.O. Box 490 Sault Ste. Marie, Ontario P6A 5M7
Aspen: ecology and management in the western United States	DeByle and Winokur (1985)	U.S. Department of Agriculture Rocky Mountain Forest and Range Experiment Station, 240 West Prospect Street Fort Collins, Colorado 80526

TABLE 3. Continued

Title	Authors	Available from:
Utilization and marketing as tools for aspen management in the Rocky Mountains	USDA Forest Service (1976)	As above
Manager's handbook for aspen in the north central states	Perala (1977)	U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station 1992 Folwell Avenue St. Paul, Minnesota 55108
Quaking aspen: silvics and management in the Lake States	Brinkman and Roe (1975)	As above
Silvical characteristics of quaking aspen (*Populus tremuloides*)	Strothmann and Zasada (1962)	As above
A review of literature relating to quaking aspen.	Heinselman and Zasada (1955)	As above
Aspen: symposium proceedings	USDA Forest Service (1972)	As above
Aspens: phoenix trees of the Great Lakes Region	Graham *et al.* (1963)	University of Mighican Press, Ann Arbor, Michigan
Silvicultural systems for the major forest types of the United States	Burns (1983)	U.S. Department of Agriculture, Forest Service, Washington, D.C. 20250
The culture of poplars in eastern North America	Dickmann and Stuart (1983)	Hickory Hollow Associates 1296 S. Clark Road Dansville, Michigan 48819

information on bigtooth aspen (*Populus grandidentata*) in eastern Canada and the Lake States and on aspen in Europe (*Populus tremula*). Information on the latter two species has been incorporated in a separate review of aspen biomass and nutrient relations, conducted on behalf of the Northern Forestry Centre, Edmonton (Peterson *et al.* 1988b). Studies of hybrid poplars and poplar plantations were also excluded because these subjects were not one of the concerns identified at the October 1987 working group meeting. Readers interested in genetics and hybridization within the genus *Populus* in the silviculture and use *of Populus* plantations should consult the recent monograph by Dickmann and Stuart (1983).

The second criterion focussed on location of the study site within the geographic range of the three target species (aspen, balsam poplar, and black cottonwood). For aspen and balsam poplar, highest priority was given to information from study sites within northeastern British Columbia and from ecologically similar hardwood or mixedwood ecosystems in Alberta, Saskatchewan, and Manitoba. Information on black cottonwood ecosystems and plantations in the lower mainland of coastal British Columbia and other study sites in Washington and Oregon was referred to only if the findings were applicable throughout the natural range of black cottonwood.

The third criterion was based on the directness with which an information source dealt with the concerns identified by the October 1987 group. Because the group sought from the literature ideas that could form the basis of interim solutions, high priority was given to information sources that contained

silvicultural guidelines and advice. Many of the references identified in Table 3 fall into this category. The geographic source of such information did not matter, provided it dealt with aspen, balsam poplar, or black cottonwood.

These criteria imply that not all references are of equal applicability to ecological conditions and hardwood forestry operations in northeastern British Columbia. For this reason, a three-class code was used in the dBase III Plus database to record the assumed applicability of the information. Each reference was rated as: (1) **relevant** – information derived from study sites within the Dawson Creek, Fort St. John, or Fort Nelson TSA's; (2) **likely relevant** – information derived from outside northeastern British Columbia, but from boreal hardwood or mixedwood ecosystems in Alberta, Yukon, Northwest Territories, Saskatchewan or Manitoba that are considered to be similar to those in the study area; and (3) **possibly relevant** – information derived from ecosystems that are ecologically distinct from those in northeastern British Columbia, often from relatively distant study sites in the southern Rocky Mountain states, Lake States, or Ontario. Information sources classed as "possibly relevant" should be used with caution until local experience confirms their applicability to the Dawson Creek, Fort St. John, and Fort Nelson' TSA's.

4 OUTDATED INVENTORY

4.1 The Problem

The working group (Appendix 1) placed a high priority on improvement of boreal hardwood inventory data because the present information does not accurately define the resource available. For example, many areas mapped as not satisfactorily restocked (NSR) or as non-commercial brush (NCBr) now support aspen-dominated stands that have present or potential value for harvesting. Detailed information on the relative proportions of hardwoods and conifers in a variety of mixedwood stands is also lacking, and refinements are needed to improve the calculations of allowable annual cuts for hardwood and mixedwood stands. The working group stressed the need for more information on hardwood growth, yield, volume, decay, waste, and utilization standards. They also called for additional ecological data on hardwood-dominated ecosystems to refine the present ecological classification system as a basis for stratifying inventory information.

4.2 Information from the Literature

The status of British Columbia's boreal hardwood inventory could not be assessed in much detail by a literature review because advances in this area are achieved by a variety of data collection programs and data analyses, rather than by publication of technical reports. For this reason, the subject of improvements to the hardwood database is discussed mainly under Sections 4.3 and 4.4.

4.2.1 Data deficiencies

Unlike those from pure coniferous or pure hardwood stands, the mensurational data from mixedwood stands are deficient. For example in describing one of the needs for the release of white spruce from trembling aspen overstoreys, Johnson (1986) identified the lack of data on the number and average dbh of aspen at various age classes in mixedwood stands. This information is important if the costs of white spruce release – particularly manual release – as well as the costs of converting aspen-dominated stands to spruce are to be refined.

The mixedwood yield tables now available do not provide the information called for by Johnson (1986), but such data exist for pure aspen stands (Bella and Jarvis 1967; Johnson 1957; Kirby *et al.* 1957). Johnson (1986) suggested that until new information is obtained from mixedwood stands the data from pure aspen stands could be applied to mixedwood stands to about age 40. New information is most critically needed for size class distributions in older mixedwood stands. Mixedwood volume information from Alberta (MacLeod and Blyth 1955) indicates that, if programs for

manual release of spruce are contemplated after age 40, there will be substantial volumes of aspen to deal with, ranging up to 350 m^3/ha at age 70 on the best mixedwood sites.

A recent assessment of available hardwood inventory data was carried out by D.R. Systems Inc. (1988) for the Inventory Branch, B.C. Ministry of Forests. The need for this analysis was evident because planning to that time had been based on information from inventories in the 1960's and early 1970's. Their review, which included data from the Ministry of Forests, Fibreco (Fort St. John), and Louisiana Pacific (Dawson Creek), noted that for several inventory type groups there was substantial over-estimation of aspen stand age in the former inventory data. Denney (1987) identified the same problem in Alberta.

The D.R. Systems Inc. analysis also revealed that for some inventory type groups the present hardwood data show poor site classes for "cottonwood" (presumably balsam poplar). This cannot be explained ecologically, since most sites occupied by black cottonwood or balsam poplar are good to excellent. Height class, in addition to site class, was often under-estimated for hardwood inventory type groups. As well, the analysis confirmed that projections of future species composition on NSR map units are highly unreliable with presently available inventory data. For example, only 1% of lands originally mapped as NSR remained as NSR. Furthermore, of the 16 inventory types that can develop on NSR lands in the audit area, 13 were found to be productive types. For lands shown as NCBr on the last inventory (1960's and early 1970's), 54% of the stands were no longer NCBr, and of those only 3% were NSR (D.R. Systems Inc. 1988).

4.2.2 Recent research

Recent efforts to improve aspen inventory methods include work in Alberta (Morgan 1987) and Minnesota (Jones 1987), and may help those seeking to improve British Columbia's estimates of volume and decay in boreal hardwoods. In the Alberta work, a type of aerial photography that would allow aspen and balsam poplar to be differentiated is being sought. Morgan (1987) described trials involving three film emulsions (black and white panchromatic, colour, and colour infrared negative films), four scales (1:5000, 1:10 000, 1:15 000, and 1:20 000), and two different times of shooting (in spring with no leaves present on the hardwoods and in summer with leaves present). Results of these trials are not yet reported. (C.Smith, pers. comm., Alta. For. Serv., Edmonton, Alta., 1988).

For yield, considered in terms of biomass rather than merchantable volume, published data suggest that culmination of mean annual increment (MAI) may occur at a considerably younger age in aspen than is generally assumed in growth and yield studies. Biomass yield tables for 10-to 90-year aspen stands in Ontario show that culmination of biomass MAI is as low as 40 years in the Boreal Forest Region (Horton 1981b). Biomass production is sustained at the maximum for a 30-year period so that harvesting may occur in stands that range from 40 to 70 years. The maximum MAI for aspen appears to be similar across a wide geographic range: Horton (1981b) estimated it at 2.2-4.7 t/ha per year in Ontario; Bella and DeFranceschi (1980) estimated it at 2.2-4.8 t/ha per year in Alberta and Saskatchewan.

Dempster (1987) and several others who presented papers at the Aspen Quality Workshop in Edmonton, Alta., stressed the need for better age class information on existing aspen stands. Concerns about aspen stand deterioration and uncertainty about how to preserve present stands for later harvest without great decay losses can best be addressed by careful regulation of age classes. For some management decisions, however, detailed age data may not be required because age information derived from fire history maps is often adequate for management purposes. Whatever the level of detail needed, the main point is that age class information is critical for aspen management, largely because decay is correlated with age.

4.3 Interim Solutions Based on Available Information

Subject to funding, the aspen inventory of northeastern British Columbia will be upgraded in the next 2 or 3 years (F. Hegyi, pers. comm., B.C. Min. For., Victoria, B.C., letter of 28 March 1988, File 160).

Meanwhile, analyses of available data are under way by the Ministry to assess the availability of aspen in that part of the province.

The task force report by Revel *et al.*(1986) suggested that decay and breakage factors for hardwoods are not very reliable because they are based on insufficient numbers of plots. Partly in response to this suggestion, the Inventory Branch recently assessed the aspen decay database for the Peace TSA and for Forest Inventory Zones K and L (memorandum from Inventory Branch to D. Nakatsu, Prince George, 7 January 1987, File 730-1). It was shown that for mature aspen, aged 81-140 years, further sampling would be needed to estimate decay and waste loss factors in the Dawson Creek Special Supply Area. As well, the Branch noted for mature aspen a difference between the levels of decay in the Fort Nelson TSA and the Dawson Creek/Fort St. John TSA's. More sampling is also required to clarify the reasons for this difference. For older-immature aspen, samples are needed in the Dawson Creek Special Supply Area to help explain differences in average percent decay between the Fort Nelson and the Dawson Creek/Fort St. John TSA's. For over-mature aspen of age classes 8 and 9 (over 141 years), however, the average percent decay is high in all diameter classes and in all combinations of external indicators of decay. Consequently, additional sampling for calculation of decay and waste loss factors is not needed for this age group.

4.4 Suggested Follow-up

The information needs identified in the Revel *et al.* task force report (1986) still exist. These include more accurate information on: height-age relationships; volume allotment checks; and decay and breakage factors. The latter were singled out by the task force as an information gap that should be addressed soon. The Inventory Branch recommended several steps to fill the knowledge gaps in the aspen decay database:

- for mature aspen (age classes 5, 6, and 7), if local decay and waste loss factors are needed for the Dawson Creek Special Supply Area, then 540 trees aged 81-140 years should be sampled within this area; and
- for older-immature aspen (age classes 3 and 4), if harvesting is planned in this age group and if local decay and waste loss factors are needed for the Dawson Creek Special Supply Area, then 240 trees aged 41 to 80 years should be sampled within the area.

Also required is the continuation of reassigning and redefining of lands formerly mapped as NSR. Many such areas have significant components of aspen that are now commercially important. Priority should be given to defining the potential productivity of lands mapped as NSR and NCBr in the inventory of the 1960's and early 1970's. That inventory's over-estimates of stand age and under-estimates of height class and site class should be addressed in any steps to improve the boreal hardwood inventory database.

5 LAND USE

5.1 The Problem

Until the recent past, the Ministry of Forests in northeastern British Columbia focussed its attention on the coniferous resource. This traditional focus is now being altered at two levels. At the broadest level, forestry uses of the land are being weighed against other uses such as agriculture, grazing, wildlife, recreation, and petroleum and hydro-electric developments. At the second level, within the forestry option, there are new land-use questions because existing or proposed commercial uses of the hardwood resource are rapidly changing the traditional concentration on conifers. Such changes require informed debate about the areas to be managed specifically for conifers, hardwoods, or mixedwood stands. As well, because the economics of converting aspen stands to coniferous stands will also change as

hardwood utilization advances, reforestation needs for managing harvested hardwood stands must be addressed.

The land base that has potential to produce hardwoods in northeastern British Columbia is facing pressure because of concurrent interests for several alternative land-use objectives: conversion to conifer forests to meet commitments to existing conifer-based wood industries; conversion to agricultural land (although this has decreased recently); and conversion to wildlife habitat, involving controlled burns. The decreasing land base available for hardwood production is of major concern because it is the source of all raw material for the proposed hardwood industries in northeastern British Columbia. Furthermore, because proposed pulp harvesting agreements have no land base tenure, long-term planning and management are severely restricted.

5.2 Information from the Literature

The discussion of land use is restricted here to land-use questions that have arisen in northeastern British Columbia and adjacent Alberta in the short time that commercial harvest of hardwoods has become widespread. The land-use literature that addresses the aspen resource furthermore is limited to a small number of key references: Telfer and Scotter (1975), Pedology Consultants Ltd. (1982), D.A. Westworth & Associates Ltd. (1984), Fox and Macenko (1985) Woodbridge, Reed and Associates Ltd. (1985), Renecker and Hudson (1985, 1986), Hudson and Frank (1987), Vicars (1988). The emphasis in this review is on information about concerns that are not yet addressed in the published literature. Some of this information came from MacLennan (1986); the rest was obtained during interviews for this project.

5.2.1 Changing attitudes

Use of boreal hardwoods as a crop represents a major shift in thinking in northeastern British Columbia where aspen, until recently, was regarded as a weed. For a long time, piling and burning was the main form of aspen management. Integrating forestry and agriculture on the same land base requires changing the attitudes of both the individual owners and managers of land (farmers or ranchers), and the regional planners and other Crown land administrators.

Changing attitudes and practices at the regional planner and Crown land administrator level is more difficult because established administrative procedures and policy directives will need to be amended in many cases. Some mechanisms are already in place to encourage this evolution. For example, the Ministry of Forests and Ministry of Crown Lands use various ad hoc committees to resolve land-use conflicts at a regional level. In addition, more formal Co-ordinated Resource Management Plans have been prepared for some areas in northeastern British Columbia.

5.2.2 Importance of extension activities

Extension activities are considered to be the key for changing attitudes and practices at the individual landowner level. For example, farm woodlots will need to be increasingly regarded as a source of hardwood crops to be managed as part of an agricultural operation. With information about hardwood management, individual landowners could be innovative in developing ways to integrate woodlots with other activities, for example, game ranching. The woodlot advisory work in Alberta (Vicars 1988) is relevant for similar co-operative forestry-agriculture land uses on private lands in northeastern British Columbia.

5.2.3 Forestry-agriculture land-use conflicts

The Extensive Agriculture Policy of the Ministry of Crown Lands is an example of how forestry-agriculture land-use conflicts are now handled. It provides landowners with a financial incentive to convert from forest land to agriculture. With a commercial market for aspen, it is now possible for a person to own a quarter-section of land after having cleared and brought 16 ha to seedbed condition. The financial incentive is a low rent (1% of market value of undeveloped land per year), which allows applicants to put their financial resources into developing the property. There are

approximately 600 Agricultural Leases in northeastern British Columbia and about 50 have been approved each year over the past 4 years. The land parcels applied for generally range from one to four quarter-sections (M. Nock, pers. comm.,B.C. Min. For., Fort St. John, B.C., 1988).

The Ministry of Crown Lands is responsible for making agriculture land available through the Extensive Agriculture Policy. During auctions of these lands, all parcels usually sell, in spite of the availability of private lands and the poor economic prospects for agriculture over the past few years. The present policy is to place the highest priority on auctioning of reverted lands. If an established farm operation meets the criteria and makes application for more land under the Extensive Agriculture Policy, the application will be considered. In the Dawson Creek Forest District such applications are processed according to the following guidelines:

i. Small parcels (usually one quarter-section) of forested land within the agricultural area are evaluated on a site-specific basis. If the land is arable, then it will eventually be used for agriculture.

ii. Larger parcels (usually four to six sections) outside the forest reserves generally require more data before decisions are made because such lands have potential for both agricultural and forestry uses.

iii. Fringe areas of Crown land adjacent to agricultural lands may be available by application if an existing operator can justify the proposed expansion. For such lands the administrative process attempts to preclude speculative applications.

For categories (i) and (ii) above, all boundaries are reviewed every 5 years, in response to demands from the potential users including the forest industries. The problem of "cut and run" speculators is not new to Crown lands that are made available for agricultural development when stumpage is low relative to lumber prices. However, this is a new problem for lands that support hardwood stands. Upward adjustment of stumpage is one mechanism to stop this type of speculation (M. Nock, pers. comm., B.C., Min. of For., Fort St. John, B.C., 1988)

Near Fort St. John, the Kobes Creek area has merchantable coniferous timber, but has been excluded from the forest reserve to meet future agricultural demands. In this case, the approach taken by the Ministry of Crown Lands is to integrate logging proposals with the planned agricultural development. Road layouts, cutblock size, and the type of post-logging treatments are planned to accommodate agricultural development. Such planning is done by ad hoc committees that, to date, have involved representatives from only the Ministry of Forests and Ministry of Crown Lands. One idea that has evolved as a result of this planning procedure is to integrate agriculture and forestry by marketing a parcel of agricultural land and a woodlot as a package. The operator would then have the potential for improved viability through diversification. A problem with this approach is that the commercial use of hardwoods is so recent that there is little experience and information to assist an operator in making sound economic decisions such as whether it is economically better to wait 10 years to log an area and continue to operate a woodlot, or to clear the land for agriculture now (M. Nock, pers. comm., B.C. Min. For., Fort St. John, B.C., 1988)

Clearly, there are two levels of land-use choices to be made for northeastern British Columbia's hardwood resource. The first choice is between forestry and non-forestry uses of the hardwood-dominated land area. Phillips *et al.* (1988) described a method used in the Peace River region of Alberta for determining the opportunity cost of removing land from timber production. If forestry is the selected use in the first level of land-use choice, then the second level of choice is between achieving pure hardwood, pure coniferous, or mixedwood stands.

5.2.4 Selecting the "best" sites for a specific use

A commonly expressed objective in the literature is that of basing certain land-use decisions on site characteristics that are "best" for a specific use. However, there are limits to which this approach is meaningful. For example, several reviews stressed that soil texture is the most important single

factor influencing the site quality of aspen-dominated ecosystems (Sutton 1958; Fralish 1972; Heeney *et al.* 1980). Other site features that researchers have singled out as characteristic of "excellent," "good," or "the best" aspen sites are summarized in Table 4. Unfortunately, the most productive forest land often has relatively good agricultural capability as well. Many of the site characteristics listed in Table 4 also represent the best sites for agriculture and for growing conifers.

5.2.5 Regional value of the hardwood resource

There are two considerations in assessing the regional value of the hardwood resource during land-use decisions. The first is the overall areal extent of the resource. The large area covered by hardwood-dominated forests in northeastern British Columbia has been well documented (Manning 1975, Bullen 1981), and needs no further comment. The second is productivity per unit area of land. For this criterion it is significant that hardwood-dominated forests include some of the most productive forest ecosystems in the region. For example, Annas (1977) described a floodplain balsam poplar association which is common along all major rivers of northeastern British Columbia. It occurs in a mid-position on young floodplains, and has the highest volumes of wood and highest site indices of any species or stands in the Fort Nelson region.

TABLE 4. Examples of site characteristics associated with good or excellent aspen growth

Site condition associated with good or excellent sites	Location	Reference
Nutrient-rich substrates, especially calcium-rich soils derived from limestone; hygric hygrotope and subeutrophic trophotope	B.C.	Krajina *et al.* 1982
Water table between 1.0 and 2.5 m below the surface	B.C.	Haeussler and Coates 1986
Water table 0.7 - 2.0 m below the surface	Lake States	Fralish 1972 Stoeckeler 1959 Wilde and Pronin 1950
Fresh to moist (good to moderate) soil moisture and sandy loam or clay loam (not sand or clay) soil texture	Alberta, Saskatchewan, Manitoba	Steneker 1976
Soils with free lime or with high calcium content	Ontario	Heeney *et al.* 1980
Silt or clay loams with a silt and clay content of 50-70% and a fresh to very fresh moisture regime	Ontario	Heeney *et al.* 1980
Silt plus clay content in excess of 31% (percent of total cubic volume in upper 1 m of soil) and depth to water table greater than 60 cm	Lake States	Brinkman and Roe 1975
Porous, loamy, humic soil with an abundance of lime	Lake States	Zehngraff 1947
Loam and silt loam soils on boulder clay or clayey moraine	Lake States	Kittredge and Gevorkiantz 1929, Kittredge 1938
Loams with heavy (clayey) subsoil and moderately high water table	Lake States	Roe 1934, 1935
Rich herbaceous vegetation	Lake States	Kittredge 1938, Roe 1934

5.2.6 The key to hardwood management

The steadily increasing demand for hardwoods suggests that there are new opportunities to harvest existing hardwood stands by clearcutting. Heeney *et al.* (1980), for example, assessing the situation of aspen in Ontario maintained that **a market for all of the existing stand is the key to hardwood management and regeneration**. The circumstances are considered to be applicable to northeastern British Columbia. The Ontario silvicultural guide for aspen management is based on the assumption that stands will be:

- managed under an even-aged silvicultural system,
- managed on relatively short rotations for a variety of pulp, paper and panelboard uses; and
- managed to maximize the benefits to wildlife through the creation of cut-block sizes, age class distributions, edges, habitat, and browse that are optimal for resident wildlife species.

5.2.7 Wildlife considerations

Where wildlife considerations affect land-use decisions, events early in the development of boreal hardwood stands are important. The first 2 years of stand development typically consist of a sucker stand that may exceed several hundred thousand stems per hectare. These dense sucker stands are important because they provide food resources for moose, deer, and hares, and cover for many other small mammals and songbirds. By the time the stand is 8-10 years old, it has usually thinned to a density of 15 000-20 000 stems per hectare. This is the stage when other wildlife species begin using these stands extensively as fall, winter, and spring cover (McNicol and Timmerman 1981; Welsh 1981; D.A. Westworth and Associates Ltd. 1984; Gullion 1984). Gullion (1984) stressed the importance of the habitat changes that accompany the "waves" of natural thinning described for aspen stands by Graham *et al.* 1963.

5.3 Interim Solutions Based on Available Information

Land use planning procedures are not readily transferable from one jurisdiction to another because of the distinctive political, regulatory, and administrative features in each. However, the recent summary of co-operative and competitive aspects of the agriculture-forestry choices on private land holdings in Alberta (Vicars 1988) is pertinent to northeastern British Columbia. The mixedwood region of western Alberta presents the same land-use choices as in the Dawson Creek and Fort St. John TSA's, including new opportunities for small private land owners to become woodlot managers. Some of the principles being applied in Alberta in the forestry-agriculture zone – such as industrial procurement of wood from owners of small private land holdings and temporary cattle grazing on forest land between the time of seedling establishment and canopy closure (Vicars 1988) – are readily adaptable to northeastern British Columbia. Application of the concepts would differ in the two jurisdictions mainly in terms of the specific administrative or regulatory mechanisms that are available locally to implement any land-use alternative.

5.3.1 Local solutions

Improvements to land-use decisions depend on local experience and knowledge such as that outlined in the recommendations by MacLennan (1986), contained in Appendix C of the task force report (Revel *et al.* 1986). The available land-use literature offers little to complement the interim solutions derived from such experience and knowledge. More recently, several local solutions to the main land-use concerns have been suggested (J. Gray, pers. comm., B.C., Min. For., Fort St. John, B.C., 1988; M. Nock, pers. comm., B.C. Min. For., Fort St. John, B.C., 1988; D. MacLennan, pers. comm., B.C., Min. For., Dawson Creek, B.C., 1988).

5.3.2 Tenure review

Recent interviews and the more detailed analyses by MacLennan (1986) show that a thorough review is needed of all long-term commitments to the land base in northeastern British Columbia. Now that boreal hardwoods are commercial species all tenures and stumpage rates for hardwoods should be re-examined. Increased stumpage rates would better reflect the potential economic benefits of longer-term forestry use of land, in contrast to shorter-term agricultural uses. As well, the Canada Land Inventory (CLI) criteria for agricultural and forestry capability should be reassessed. MacLennan (1986) believed that as much as half of the estimated 100 000 ha of category 2 lands, which until recently have been viewed as lands for potential expansion of ranching or farming, could be justifiably redefined as forest lands (category 3) now that commercial use of aspen is a reality. If this reclassification were to occur, up to 50 000 ha could be added as forest land to the Wapiti and Moberly forest reserves.

5.3.3 Review of the Extensive Agriculture Policy

Another solution is a review of the Extensive Agriculture Policy of the Ministry of Crown Lands. With the downturn in the farm economy of the past few years, there are presently enough private lands to meet agricultural needs. Yet, despite the current low prices for agricultural land and the availability of private land, there is still a demand for agricultural leases. This should be met by the marketing of leases that have reverted to the Crown, rather than by the creation of new ones. As well, there have been suggestions that the private woodlot program be used to maintain the forest land base on private lands. One element of this would involve determining whether stumpage could be deferred on non-arable portions of an agricultural lease. Another suggestion, from MacLennan (1986), was that the Small Business Program of the Ministry of Forests be extended to the aspen component of the Louisiana Pacific PHA.

5.3.4 Investments in forest land

According to interviewees, investments in forest land, such as conifer planting and site preparation, should only be undertaken where there is a reasonable likelihood of harvesting the future forest crop. For example, after an area has been logged, the agricultural capability of the land should be re-evaluated. If there is the possibility of future conversion to agricultural use, boreal hardwood species should be considered as acceptable regeneration because hardwoods can be marketable in a relatively short term – perhaps as little as 30 years. Investments into conifer establishment should only be made where there is little chance of agricultural demand for the land before the next rotation. Within existing agricultural lands, non-arable portions could be managed as woodlots for hardwoods. All of these suggestions point to the importance of flexibility in encouraging more rational management of the land base. One element of such land management is planning forestry roads to facilitate agricultural development.

5.3.5 Securing the forest land base

One of the most important interim solutions, identified in the task force report by Revel *et al.* (1986), is to secure the forest land base in the parts of the Dawson Creek, Fort St.John, and Fort Nelson TSA's where boreal hardwood management is to be the dominant land use. Already there have been proposals for adjusting forest reserve boundaries to increase this forest land base. Another suggested step is to re-assess present silvicultural commitments within the Louisiana Pacific PHA. For example, the major commitment of the Canada-British Columbia Forest Resource Development Agreement (FRDA) to convert 10 000 ha of NSR and other aspen-dominated land to conifers may no longer be an appropriate step. The task force report (Revel *et al.* 1986) suggested that all cutting permits on Crown land in a radius comparable to the wood procurement area of Louisiana Pacific should require obligatory use of both boreal hardwoods and conifers. Future proposals for stand conversion will probably be the most controversial of all land-use alternatives to be debated.

One suggestion by MacLennan (1986), which would represent a major departure from present policy, is for the Crown to buy back certain marginal agricultural lands, in circumstances where reversion to the Crown is likely to occur anyway because of unsustainable agricultural use of the land. Converting these lands could be accomplished under Section 4 of the Forest Act, but such a step is unlikely to be accepted politically without substantial support from local communities and individual landowners.

5.3.6 Control of range burning

Range burning for forage management is a common practice that would need to be curtailed if long-term hardwood management becomes the main land use. As an interim measure, MacLennan (1986) recommended that lands suitable for aspen harvesting or conversion to aspen be identified in burning plans and safeguarded during burning operations. However, Revel *et al.* (1986) noted that range burning of aspen stands is thought to have a significant negative influence on the growth of aspen--although the ecological effects are not well documented in environments similar to those in northeastern British Columbia. A review of the burning practices promoted by other agencies of the British Columbia government should be carried out to assess the overall impact of burning on boreal hardwood regeneration.

5.3.7 The need for new land use strategies

The introduction of commercial aspen harvesting requires substantial changes to regional and district management policies in timber, range, silviculture, and protection programs. Existing programs and 5-year management plans are influenced by the new range of land-use conversion options that now exist, including aspen to agriculture, aspen to range, aspen to conifer, aspen to aspen, forest land to agricultural land, and agricultural land to forest land (MacLennan 1986). Revel *et al.* (1986) identified the need for interim land-use strategies, and noted that even before Louisiana Pacific made commercial demands for local boreal hardwoods the Dawson Creek and Fort St. John TSA's were undergoing changes in response to 20 year planning and the re-evaluation of yield analysis. As well, the proposal for Tree Farm License 48 in this area created the need for an additional allowable annual cut that would require the rehabilitation of large areas of lands designated as NSR or NCBr. A major concern of these dynamic land-use changes is the protection of allowable annual cuts of established conifer licenses in the Dawson Creek and Fort St. John TSA's. However, such protection would require considerable species conversion from aspen to spruce on the best sites within the Louisiana Pacific PHA. Clearly, the designation of the land base to appropriate use remains an important unresolved issue.

5.4 Suggested Follow-up

The most urgently needed follow-up steps, some of which are already in progress, have been identified by MacLennan (1986):

- re-assessment of boundaries of the Wapiti and Moberly forest reserves within the Louisiana Pacific PHA
- assessment of existing and potential tenures and commitments within the Louisiana Pacific PHA
- provision of assistance and encouragement to the concept of Farm Woodlots and Aspen Woodlot Licences within category 1 and category 2 lands of the Louisiana Pacific PHA
- review of the various range tenures (Annual Grazing Permits, Term Grazing Permits, Grazing Licences, Grazing Leases, and Range Reserves within Coordinated Resource Management Plans), with particular attention given to the fact that 50% of the available forage exists under aspen and mixedwood stands,

a major portion of which involve aspen age classes suitable for harvesting and which are within the operating radius of the Louisiana Pacific plant in Dawson Creek

- review of existing timber tenures including Tree Farm Licence 48 and Woodlot Licence 914, with emphasis on ways to integrate boreal hardwood utilization with existing timber management policies. The issues involved here, as outlined by MacLennan (1986), are complex and involve details of allowable annual cut calculations, stand conversion (aspen to coniferous or aspen to aspen), and criteria for consideration of NSR and NCBr lands in calculations of allowable annual cut.

Reference to the Louisiana Pacific PHA above is not meant to imply that the identified land-use concerns are limited to only that part of northeastern British Columbia. Similar land-use questions exist elsewhere there. The specific issues will vary with the details of present tenures and commitments, and with the competing land-uses that exist in any given area.

5.4.1 The importance of ecosystem classification

As emphasized by Revel *et al.* (1986), ecosystem classification of hardwood-dominated sites in northeastern British Columbia is a prerequisite for land-use decisions. Refinement of the existing ecosystem classification for aspen types is required not only for land-use planning, but also for development of reforestation guidelines and prediction of regeneration response. One step in this direction is the recent field guide for identifying and interpreting seral aspen ecosystems in a portion of the Moist Warm Boreal White and Black Spruce Variant in the Prince George Forest Region (DeLong 1988). As interest intensifies for boreal hardwoods, there will need to be more winter and early spring aerial photography to aid the differentiation and mapping of aspen and balsam poplar. There should also be more ground sampling to complete the ecological classification of the area, as well as more effort to link productivity with the classification units.

6 LACK OF AWARENESS OF HARDWOOD UTILIZATION AND MANAGEMENT OPPORTUNITIES

6.1 The Problem

Hardwood utilization is sufficiently new as a land-use activity in northeastern British Columbia that it generates considerable anxiety amongst those who are not yet well informed about it. Not only forest practitioners, but farmers, ranchers, and the general public, need information on the opportunities and problems associated with hardwood use. Experience elsewhere has resulted in much information about boreal hardwood use and management, but it needs to be in a form that is useful to the main resource users. New questions will arise as operators try to decide whether to use aspen or balsam poplar (much of it over-mature with high proportions of decay) during harvesting operations originally intended for only coniferous removal. Existing woodlot managers, as well as farmers and ranchers who are contemplating the harvest and sale of hardwoods on lands of marginal agricultural value, are potential beneficiaries of an improved information dissemination system. The present review is one step towards that goal but, as suggested in Section 6.4, several other extension, education, and demonstration initiatives are needed.

6.2 Information from the Literature

Large forestry corporations are well aware of the utilization potential of boreal hardwoods. This is partly because of the well-established system of getting information to industrial users, as shown by the impressive array of recent literature on boreal hardwood use (Maini and Cayford 1968; Bailey 1973; Keays *et al.* 1974; Neilson and McBride 1974; USDA Forest Service 1976; Brese 1977; McIntosh and Carroll 1980; Soos 1981; Whitney and McClain 1981; Woodbridge, Reed and Associates Ltd. 1981, 1985;

Alberta Research Council 1983; Carroll-Hatch (International) Ltd. 1983; Singh and Micko 1984; Arbokem Inc. 1986, 1987; H.A.Simons (International) Ltd. 1986; Lepper and Keenan 1986; Wengert 1986, 1988; Canadian Forestry Service and Alberta Forest Service 1987). For this literature review, the most informative of these background reports are the *Aspen Quality Workshop* (Canadian Forestry Service and Alberta Forest Service 1987), the hardwood utilization review prepared for the Northern Alberta Development Council by Woodbridge, Reed and Associates Ltd. (1985), and the aspen utilization and marketing review carried out by Wengert (1988) under the Canada-Alberta Forest Resource Development Agreement. In addition, Kennedy's review of *Populus* wood properties in relation to use (in Neilson and McBride 1974) provides a good overview. Highlights of these reports are summarized below.

6.2.1 *Populus* wood qualities

Poplars are low-density, diffuse-porous hardwoods. Their vessels are generally small enough to allow surface finishing without a filler treatment, being similar to birch or maple in this regard. The vessels also enhance the smoothness and opacity of poplar pulp, which is an advantage for the production of fine printing papers (Kennedy 1974).

The specific gravity of most poplars is the same as the average for white spruce (0.354) and significantly less than that of white birch (0.506). Thus, about the same weight of poplar wood can be contained in a pulp batch digester as spruce. The relatively low specific gravity of poplars results in only moderate strength for sawn lumber, but is an advantage in the manufacture of particleboard or flakeboard, since moderate pressure brings individual particles into contact and ensures a medium-density board with good strength. In general, nail-holding power varies with specific gravity, so that poplars have about the same ability as white spruce to hold nails and other fastenings (Kennedy 1974).

Tension wood, common in poplar, is characterized by masses of gelatinous fibres which can result in Alpha cellulose yields as high as 60% of the weight of the wood. This high cellulose content is not always advantageous, however, since longer pulp beating times may be required to reach a given "freeness level", and some strength properties may change. Tension wood in poplars also has a significantly higher longitudinal shrinkage than normal wood. This can lead to bowing, crooking and more severe checking in lumber, and buckling of veneer upon drying, particularly if large streaks or areas of tension wood are present (Kennedy 1974).

The carbohydrate content of poplars is remarkably high and the lignin content correspondingly low. As a result, sulfate pulp yields are in the range of 52-56% of the dry weight of wood, compared to about 44% for most softwoods and 50-52% for other hardwoods. However, the crushing strength of poplar wood is low for its specific gravity, presumably due to the relatively small amount of lignin. The extractive content of poplar wood is also low and not toxic to fungi, making the wood susceptible to decay unless treated with a preservative for high-hazard situations. A laboratory study of the deterioration of stored aspen pulp chips indicated a loss of wood substance of about 1% per month over a 6-month period. The net result of this loss was a decrease in pulp yield from 56.0 to 52.6%, based on the original wood available (Kennedy 1974).

Standing poplar trees have a high moisture content, typically about 100%, which differs between sapwood and heartwood. Seasonal fluctuations exist, such that moisture content in the summer months may be 30-50% lower than that of late winter. Variation also exists between species, with black cottonwood and balsam poplar generally having higher amounts of moisture than aspen. Seasonal and species variations make it difficult to develop a consistent drying schedule (Kennedy 1974).

6.2.2 Decay in *Populus* wood

Decay is commonly encountered in living trees of all poplar species and results in reduced yields for pulpwood, veneer, and sawlogs. Black cottonwood stands are estimated to have between 32 and 77% of their trees measurably decayed by ages 80 and 180 years, respectively (Thomas and

Podmore 1953). At a maturity of 70 years for trembling aspen and 110 years for balsam poplar on good sites in Alberta, aspen is about 25% decayed and balsam poplar about 12% (Thomas 1968). Most of the decays of poplar are induced by white-rot fungi, which generally attack all wood components simultaneously. Another type of heartwood discoloration in poplars, often associated with bacteria, is termed "wetwood". This usually occurs as an irregular zone between the sapwood and heartwood, and is usually characterized by a darkened appearance and somewhat higher moisture content (Kennedy 1974).

Decay is of paramount importance in hardwood use. The defect level in aspen can directly affect whether the resource is economical to pulp (Breck 1987; MacLeod 1987). Alberta studies indicate that white heart rot (*Fomes igniarius*) is the most common decay organism. It is more prevalent in aspen than in balsam poplar (Woodbridge, Reed and Associates Ltd. 1985). Although the significance of decay to commercial use of aspen is well documented (Table 5), one major problem is how to predict the extent of decay in existing or future hardwood stands. A further complication is that decay is unpredictably distributed throughout the tree. This means that if only 10-20% of the wood is rotten manufacturers still have difficulty recovering the sound wood economically. Timing is critical in the successful use of aspen: the trees must be harvested after they are large enough for manufacture, but before decay is well advanced (Woodbridge, Reed and Associates Ltd. 1985).

TABLE 5. Impact on wood quality, allowable amount of stain or decay in the product, and extra manufacturing cost for each 10% increase in incidence of stain, incipient decay, and advanced decay for various products manufactured from aspen (Source: Breck 1987)

Product	Level of stain or decay	Impact on wood quality	Allowable amount in product	Extra manufacturing cost for each 10% in stain or decay
Bleached chemical pulp	Stain	None	Unlimited	0%
	Incipient decay	Reduces yield and strength; higher boiler loading	N/A	2%
	Advanced decay	Reduces yield; higher chemical costs and boiler loading	N/A	4%
Bleached high yield pulp	Stain	Increases cost; reduces brightness and selling price	10-15%	3%
	Incipient decay	Increases cost; reduces yield, brightness, and selling price	0-5%	5%
	Advanced decay	Increases cost and effluent treatment; reduces yield, strength brightness, and selling price	0-1%	5-7%
MDF/ particle-board	Stain	None	Unlimited	0%
	Incipient decay	Reduces strength, machineability and nail-holding capacity	20-40%	0%
	Advanced decay	Reduces yield	0-5%	2.5%

TABLE 5. Continued

Product	Level of stain or decay	Impact on wood quality	Allowable amount in product	Extra manufacturing cost for each 10% in stain or decay
Oriented strand board	Stain	Impairs appearance and reduces marketability	20-30%	0%
	Incipient decay	Reduces strength	10-20%	0%
	Advanced decay	Reduces yield	0%	2.5%
Construction lumber	Stain	None, but appearance may affect marketability	25%	0%
	Incipient decay	Reduces strength and grade	10-20%	5%
	Advanced decay	Reduces strength and yield; downgrades product	0-10%	5-10%
Furniture and specialty lumber	Stain	Impairs appearance	0-10%	0%
	Incipient decay	Impairs appearance and reduces strength	0-10%	5-10%
	Advanced decay	Impairs appearance and reduces strength	0%	5-10%
Small specialty products (chop-sticks & popsicle sticks)	Stain	Reduces yield; product is unmarketable	0%	2-4%
	Incipient decay	Reduces yield; product is unmarketable	0%	2-4%
	Advanced decay	Reduces yield; product is unmarketable	0%	2-4%
Plywood and veneer	Stain	Restricts veneer to core of plywood	30%	0%
	Incipient decay	Reduces yield and strength; restricts veneer to core of plywood	10%	2-5%
	Advanced decay	Reduces yield and operating efficiency	0%	5-10%

6.2.3 Options for use of aspen raw material

The Woodbridge review ranked several aspen product options that appeared to have the greatest investment potential in northern Alberta. The pulp and paper development options were:

Option	Development potential (on technical grounds)
Aspen bleached kraft pulp	High
Bleached CTMP	Medium-high
Uncoated woodfree papers	High
Uncoated groundwood papers	Medium
Lightweight coated paper	Medium
Tissues	Low
Newsprint	Low

The rankings for wood product development options were:

Option	Development potential (on technical grounds)
Waferboard (oriented strand board)	High
Construction plywood	Medium
Medium density fiberboard	High
Particleboard	High
Specialty plywood	Medium
Industrial handling lumber	High
Reconstituted lumber	Medium
Specialty lumber	High-medium

Excluding the possible development of specialty pulp and paper products, the overall assessment of the potential for Alberta's hardwood resource (Woodbridge, Reed and Associates Ltd. 1985) was as follows:

Most promising

- Aspen/softwood CTMP
- Lightweight coated paper
- Bleached aspen kraft market pulp
- Specialty lumber

Longer term potential

- Uncoated groundwood papers
- Uncoated woodfree papers
- Waferboard (oriented strand board)

Possible, but not given a high ranking

Newsprint
Tissues

One limitation to the development of specialty aspen lumber products is the requirement for very high quality logs. Such aspen logs are available on some sites but their use would be economical only if small operators could log them selectively. This could present problems because clearcutting, rather than selective logging, is considered to be a prerequisite for good regeneration of aspen. Another difficulty with selective removal of high quality aspen logs is that they are often difficult to identify until the tree has been felled and bucked (Woodbridge, Reed and Associates Ltd. 1985).

Pulp, paper, waferboard, and particleboard are the uses most widely recognized for boreal hardwoods. Less well documented are several uses reviewed by Wengert (1988) for Alberta aspen. He rated eight possible uses for Alberta aspen--excluding pulp, paper, waferboard, and particleboard--according to overall technical and marketing potential:

Product	Overall potential
Veneer and plywood	Product value is high, but manufacturing costs are very high; market development would be necessary; high quality resource probably lacking.
Construction lumber	Very low product value; very low yields; many unsuccessful industrial trials.
Utility lumber	Moderate to high potential for high quality logs over 24 cm in diameter; profitable residue uses are essential.
Furniture blanks or parts	High potential for medium and high quality logs; some market development needed; product value is high.
Pallet stock or parts	High potential, especially with profitable residue use; already active markets in Alberta.
Fuel	Low potential for development of markets; low weight per volume is a problem; briquet manufacturing possible.
Animal feed and roughage	Interesting possibilities, but many unanswered questions, including safety of animals and humans.
Animal bedding	High potential for all grades of logs; markets must be within 100 km of resource.

6.2.4 Pulp production from aspen

For chemical pulps, aspen fibre is ranked as the third highest in quality amongst the world's hardwood species, after eucalyptus and white birch (Breck 1987). Aspen is an excellent fibre for the production of printing and writing paper from high-yield pulp. However, rotten wood, incipient decay, and stain are less tolerable in solid wood products. For example, a patch of rotted wood on a 2 x 4 stud will downgrade the entire stud; the same amount of defect blended into the homogeneous mix that makes up pulp may be acceptable.

Advanced rot, which attacks the cellulose structure in the wood, has two effects on aspen use. The first is a reduction in fibre yield per cubic meter of wood; the second is a reduction in the intrinsic strength of the fibre. Although the kraft pulping process is the most forgiving of any of the pulping processes, even kraft mills cannot use raw materials in which advanced rot has progressed to total rot. If rotten aspen logs do get into the kraft chipping process, most of the rotted raw material can be

removed without harming the mill; there is, however, an economic effect because the operator has paid to bring wood to the mill, chip it, and then discard it (Breck 1987). Mechanical pulping is more sensitive than the kraft process to the quality of raw materials. Aside from the loss of yield when rotten logs are used, stain and incipient decay require the use of more bleaching chemical, which is extremely expensive. Brightness level of mechanical pulp is critical if it is to break into the markets now held by kraft pulps (Breck 1987).

Industries currently involved with aspen pulp production need high quality wood, and this requirement has important implications for aspen stand management. For example, stands must be cut before there are significant amounts of incipient decay. Barr (1987) cautioned that if aspen is managed on the traditional "cut-the-oldest-first" sustained-yield policy, or based on conifer utilization standards, then the aspen industry will be stifled. Since aspen pulp generally commands lower prices than coniferous pulp, the delivered cost of aspen is critical. There is a need to achieve the highest yields possible from delivered aspen, and that requires logs with little or no rot.

6.2.5 Oriented strand board production from aspen

High quality oriented strand board (OSB) requires relatively fresh aspen wood. Rot causes several problems:

1. During waferizing, stained wood and rotten wood do not cut cleanly.
2. In summer, rotted portions of logs tend to soak up water more rapidly than surrounding wood, creating additional energy requirements to dry the rotted material.
3. Rotted ends of logs harbour more sand and stones than normal wood, and these impurities shorten the life of the waferizing knife.
4. In the blending phases of OSB production, the fines that result from rotted wood require more resin than normal; wafers of rotted wood soak up resin rather than keeping it on the surface to create a bond. The reduced surface bonding is accompanied by lower bending strengths in boards that contain rotted wood.
5. The light surface colour now preferred by users of OSB products is difficult to achieve if there is stain and rot in the raw materials (Anderson 1987).

Despite these concerns, the OSB process tolerates rot in aspen better than does clear lumber production (Denney 1987). For example, Pelican Spruce Mills Ltd. at Edson, Alberta, uses aspen logs that contain up to 50% incipient or advanced decay. The decay, however, is not allowed to become part of the board, but goes to wood waste that is used as fuel for drying strands. It is at the harvest end of an OSB operation that cull is so important, because logging and hauling are paid for on a firm-wood basis. If cull is 15%, the rate of earnings is reduced by that amount (Denney 1987).

6.2.6 Harvesting and transportation considerations

Another key participant in any new industrial initiative for hardwood use is the contracting industry that harvests and moves raw materials to the processing plants. This sector presumably operates in unison with the processing plants it serves and therefore is not expected to have an awareness problem associated with the harvesting and transportation of hardwood raw materials. However, contractors may not realize what new opportunities they have to become involved with various aspects of hardwood silviculture, because it differs so markedly from site preparation and regeneration in coniferous stands. Supervising contractors during hardwood harvesting operations will likely require new initiatives by Ministry staff – particularly when the goal is to protect understorey spruce during the removal of mature aspen, or to harvest in ways that maximize hardwood regeneration.

6.2.7 Silviculture-utilization relationships

Relationships between silviculture and utilization are complex. For example, utilization potential affects decisions about when and where to release conifers from aspen competition. In this context, guidelines developed by Johnson (1986) for Manitoba mixedwood stands are relevant for northeastern British Columbia. He suggested that because use may change considerably in the near future, first priority should be given to releasing older understorey spruce (40-70 years) to give a relatively quick return. Converting good site aspen stands into coniferous stands may be expensive and imprudent, whether it is done by reforestation or by releasing young established spruce. The ideal situation, according to Johnson, would be to use the aspen commercially while releasing the understorey spruce. Attention should also be given to encouraging the exchange of hardwood and softwood harvested material amongst large operations that presently use only one of these resources. Timber sales, in which small operators separate hardwoods from conifers and market each separately, could possibly serve as a prototype approach for larger operations (C. Wilson, pers. comm., B.C. Min. For., Dawson Creek, B.C., 1988).

6.2.8 The role of woodlot owners

Other suppliers of the hardwood resource – the private landowners with harvestable aspen – are the most likely target for improving the awareness of hardwood use and management opportunities. Extension activities, including demonstration areas for woodlot management, and well-written, illustrated manager's handbooks would be the key tools to reach this audience. Several aspen-related handbooks or monographs serve as models (Jarvis 1968; Steneker and Wall 1970; Brinkman and Roe 1975; Steneker 1976; Perala 1977; Tubbs 1977; Heeney *et al.* 1980; F.H. Berry 1982; Perala and Russell 1983; Shepperd and Engelby 1983; Ontario Ministry of Natural Resources 1984; DeByle and Winokur 1985; Shepperd 1986). However, no handbook exists that is entirely suitable for use in the ecological setting of northeastern British Columbia.

6.3 Interim Solutions Based on Available Information

There are no immediate interim solutions to the dissemination of existing information because extension, education, and demonstration are long-term activities. Seminars and field demonstrations of aspen management, already proposed by Revel *et al.* (1986), will be important to increase the awareness of opportunities involved with boreal hardwood management.

6.4 Suggested Follow-up

The earliest follow-up activities should be directed at private landowners who are potential suppliers of hardwood raw materials, and should be either informative extension leaflets or handbooks suitable for outdoor use. The key objective of this first step would be to assemble information that would assist the management and use of the hardwood resource. If a handbook is prepared, special attention should be given to the ecological conditions of British Columbia's boreal hardwood stands, which may differ from those in the prairie provinces, Lake States, or other regions that have already produced an aspen manager's handbook. Recommended procedures should be tied to ecological units that have already been described for forested ecosystems in northeastern British Columbia. The suggested extension materials should focus on the regeneration, decay, and harvesting aspects of aspen management. Such a handbook must be well illustrated with local photographs. Also, in addition to the preparation of an aspen manager's handbook, the seminars and demonstration areas already suggested by the working group should be initiated.

7 HARDWOOD STOCKING STANDARDS

7.1 The Problem

Stocking standards have traditionally been assessed by surveys of coniferous regeneration on plots having few, if any, deciduous tree seedlings "acceptable" as countable seedlings. Determining whether regeneration obligations have been met, however, would be different if hardwood seedlings or suckers became acceptable for the next forest crop. Minimum and target standards must be defined for hardwood stocking in areas designated for management as boreal hardwood or mixedwood forests.

7.2 Information from the Literature

7.2.1 Stand density data

There appears to be a wide range of acceptable early stand densities for aspen. One reason may be the tendency for stands to end up with a relatively similar density, in the range of 20 000-25 000 stems per hectare by approximately age 6, whether sucker density the 1st year after harvesting is as low as 44 000 or as high as 225 000 stems per hectare (Table 6). For example, Bella (1986) noted that sucker density after the first growing season was twice as high after summer logging (exceeding 200 000 stems per hectare) as after a winter cut. However, these large initial differences in stand density diminished to 30% or less 5 years after harvesting. The same relative range of densities remained to age 17 years in Bella's study area at Hudson Bay, Saskatchewan.

Brinkman and Roe (1975) reported that 15 000-30 000 well-distributed suckers per hectare are preferable to young stands with 85 000-100 000 stems per hectare. Results of a Minnesota thinning study in 1- year-old aspen suckers indicated that as few as 15 000 stems per hectare may be adequate. Where stocking had been reduced from 25 000 to 2500 stems per hectare, Sorensen (1968) reported that basal area increased almost as much in 15 years as it did in an unthinned stand. Average tree diameter was 2.5 cm greater in the thinned stand, but the gain in average diameter for the 400 largest trees per acre was only 1.0 cm. After 20 years, the unthinned stand contained more volume per hectare, although average tree diameters were still less than those in the thinned stand. Moreover, part of the increase in average diameter must be attributed to removal of small trees, and thus the benefits did not justify the substantial costs of thinning.

7.2.2 Sucker production in relation to density of parent stand

Sucker production is affected by stocking of the parent stand before cutting. Poorly stocked aspen produce few suckers after logging, because they do not have the necessary root densities. In Michigan, Graham *et al.* (1963) found the following relationship between the basal area of parent stands and mean sucker production 1 year after clearcutting: less than 11.48 m^2/ha, 12 850 suckers per hectare; 11.49-22.96 m^2/ha, 17 300 suckers per hectare; and more than 22.96 m^2/ha, 24 450 suckers per hectare. DeByle and Winokur (1985) believed that 50 000-74 000 suckers per hectare is not excessive, because early natural thinning is rapid. The least vigorous suckers die during the first 2 years, leaving one or two dominant suckers in each clump. Competition reduces most clumps to a single stem by the 5th year after cutting, and almost all to a single stem by the 10th year (Sandberg 1951; Turlo 1963).

7.2.3 Influence of early stand density on height growth

Strothmann and Heinselman (1957) examined how stand density influenced survival and height growth of suckers during the first 10 years after clearcutting of aspen in Minnesota. The studied sucker stand had arisen following commercial clearcutting of the parent stand in the fall and winter of 1950. In July of 1951, all non-merchantable residual aspen and hardwoods were removed to avoid irregularities in sucker distribution due to overstorey shading. The study involved five levels of stocking (642, 1235, 2470 and 3706 stems per hectare) and a check area which averaged about 24

860 stems per hectare. New suckers that came up were removed annually except on the check plots. Survival and height growth data by treatments are reproduced in Table 7. The authors concluded that stand density has little effect on the height growth of aspen during the first 5 years, and that survival of aspen suckers decreases with increasing stand density. When aspen stands are thinned immediately after establishment, additional suckering can be expected for at least 3 years (Strothmann and Heinselman 1957).

TABLE 6. Number of aspen suckers per hectare in relation to age

Reference (location)	Age (years) 1	2	3	4	5	6	7	8	9	10	17
Crouch 1983 (Colorado)	76 758	74 198	55 285	36 176	24 513	20 707	17 816	–	–	–	–
Crouch 1981 (Colorado)	–	–	–	–	–	18 021	13 135	10 959	7 455	6 417	–
Perala 1984 (Minnesota)	128 045	91 095	63 765	43 510	29 790	22 005	16 190	–	–	–	–
Weingartner 1980 (Ontario)	46 800	41 400	31 400	–	–	–	–	–	–	–	–
Pollard 1971 (Ontario)	–	–	–	31 000	29 000	26 000	22 000	–	–	–	–
Bella 1986 (Saskatchewan)	74 000	59 000	48 000	47 000	38 000	27 000	–	–	–	–	9 000
Steneker 1976 (Prairie provinces)	225 000	162 000	130 000	85 000	50 000	–	–	–	–	–	–
Steneker 1976 (Prairie provinces)	44 000	40 000	35 000	33 000	29 000	21 000	–	–	–	–	–
Bella and DeFranceschi 1980 (highest density class, Alberta/ Saskatchewan)	–	280 000	190 000	125 000	80 000	–	–	–	–	–	–
Bella and DeFranceschi 1980 (lowest density class, Alberta/ Saskatchewan)	–	160 000	110 000	75 000	50 000	–	–	–	–	–	–

Several agencies are currently developing stocking standards – including the Ministry of Forests, for the Prince George Forest Region, and the Alberta Forest Service (Henderson 1987)– though no reports are yet available. Clause 22(6) in the Weldwood of Canada Ltd. hardwood management agreement in Alberta allows deciduous species to be counted as acceptable in regeneration survey plots, in reverse ratio to the acceptable conifer-deciduous proportions traditionally used in coniferous regeneration surveys.

TABLE 7. Survival and height growth of aspen suckers under various stocking levels (Source: Strothmann and Heinselman 1957)

Treatment: stems left per hectare 1952[a]	No. stems per per hectare 1956	Survival[b] (%) 1953	1954	1955	1956	Average height (m) 1952	1956
642	593	94.9	92.3	92.3	92.3	1.28	3.17
1 235	1 087	97.3	97.3	88.0	88.0	0.91	2.10
2 470	2 256	98.7	96.0	91.3	91.3	1.10	2.99
3 706	3 096	94.7	90.3	85.8	83.5	1.34	2.96
24 860 (check)	13 837	66.1	69.4	64.4	55.7	0.73	2.44

[a] Maintained at this level annually on all except check plots, by the removal of new suckers.
[b] Percent of the original number of stems.

7.2.4 Aspen stocking standards in other regions

Until recommended standards are developed and tested for northeastern British Columbia, stocking standards specified in Ontario's silvicultural guide for aspen might be used:

> .....6000 aspen stems per acre (14 800 stems per hectare) will give 90% stocking by mil-acre quadrats. Adequate stocking of 80% at 5 years of age can be obtained from as few as 1000 stems per acre (2500 stems per hectare), if they are uniformly spaced over the area. Very high density stands up to 60 000 stems per acre (148 000 stems per hectare) are sometimes encountered. This high stand density is reduced rapidly through natural mortality to: 5000 to 6000 stems per acre (12 350 to 14 800 stems per hectare) at 5 years of age and 1000 to 1200 stems per acre (2500 to 2960 stems per hectare) at age 20.
>
> Stocking Standards
>
> i Regeneration period: five years
>
> ii Acceptable species:
> - primary: aspen of good quality
> - secondary: spruce, white pine, balsam, white birch, jack pine.
>
> iii Desireable stocking:
> The following conditions should be met:
> - more than 80% of stand should be aspen.
>
> iv Desireable trees per acre:
> - more than 6000 aspen trees per acre (14 800 stems per hectare).
>
> v Failure:
> If any of the following conditions apply:
> - less than 50% stocking of aspen:
> - poor quality aspen.
>
> vi Release: not required. (Heeney *et al.* 1980)

The current update of Ontario's *Silvicultural Guide to the Poplar Working Group* (Davison *et al.* 1988) makes the following recommendation: "Forest renewal operations are not normally required for the successful establishment of a new forest of aspen. Clearcutting followed by natural aspen regeneration will normally provide adequate stocking and growth." Nevertheless, free-to-grow standards for forest renewal of aspen in Ontario have been established. The following free-to-grow benchmark standards have been specified by Davison *et al.* (1988) for aspen regeneration in northwestern Ontario:

Renewal treatment: natural

Free-to-grow minimum stocking: 60%

Objective stocking: 70%

Acceptable species: aspen

Minimum total height: 1.0 m

Recommended time of assessment: 3 years

For the prairie provinces, Steneker (1976) suggested that, for fibre production, a stocking of 6000 evenly-spaced suckers per hectare during the 3rd year after harvesting would be adequate; for lumber production, he recommended around 2500 stems per hectare at age 3. For Ontario, Hambly (1985) suggested that at age 5 years a minimum of 2500 well-spaced stems per hectare should give 80% stocking, but the preferred goal is 15 000 well-spaced stems per hectare for 80% stocking.

Table 8 summarizes two examples, one each from Alberta and Ontario, of numbers of trees per hectare required for full stocking at various ages in pure aspen stands. These data may be of only limited applicability to aspen stands in northeastern British Columbia; stocking standards are site specific and need to be tied to local yield tables for fully stocked stands.

TABLE 8. Number of trees per hectare, by age class on good, medium, and poor sites, in fully stocked stands of pure aspen in Alberta and Ontario

Age	Grande Prairie to Lac La Biche, Alberta (MacLeod 1952)			Ontario (Plonski 1956)		
	Good	Medium	Poor	Good	Medium	Poor
10	14 900	19 000	24 710	–	–	–
20	9 270	12 350	17 000	2 525	3 054	4 119
30	6 180	8 150	11 600	1 724	2 184	2 965
40	4 150	5 530	8 030	1 255	1 648	2 236
50	2 900	3 830	5 400	961	1 285	1 724
60	2 100	2 700	3 830	758	1 018	1 359
70	1 560	1 950	2 700	625	825	1 104
80	1 160	1 480	1 950	536	692	931
90	910	1 150	1 500	477	608	818
100	730	940	1 220	442	556	746
110	605	790	1 040	–	–	–
120	518	682	914	–	–	–

7.3 Interim Solutions Based on Available Information

The task force request for a review of current stocking standards (Revel *et al.* 1986) is still applicable. New standards and species selection guidelines for hardwoods require further refinement in those areas of northeastern British Columbia where hardwood harvesting is going to proceed most rapidly. Until such refinements are available, the standards used in Ontario could be adopted in northeastern British Columbia. However, because stocking standards are site specific, they must only be used as a guide to assess the standards presently being drafted for the Prince George Forest Region.

7.4 Suggested Follow-up

The task force suggestion that stocking standards be implemented for individual cutblocks (Revel *et al.* 1986) would be difficult to undertake now. Additional ecological site classification and development of pre-harvest silvicultural guidelines must first be done if each cutblock is to receive an individual prescription for desired species, in relation to stocking standards and according to ecosystem characteristics. Developing such guidelines should be done gradually, with attention given first to cut blocks on those ecosystems expected to support the most productive hardwood or mixedwood stands. The task force suggestion that trials be started immediately to assist in the development of stocking standards for aspen on a range of sites is strongly supported.

7.4.1 The need for locally-generated stocking standards

The draft stocking standards and guidelines for the Prince George Forest Region contain different "free-to-grow" benchmark standards than those specified by Davison *et al.* (1980) for Ontario. Aspen is a preferred species for stocking, along with white spruce and/or lodgepole pine, in some biogeoclimatic units of northeastern British Columbia (Ecological Units 01, 05, and 06 of BWBSc1, c2, d1, and d2). For those units, the draft guidelines for northeastern British Columbia specify 6 years as the earliest date at which aspen could be declared free-growing, and 9 or 12 years as the latest date. Target annual leader growth of free-growing crop trees on wetter sites is 80 cm for balsam poplar and black cottonwood and 60 cm for aspen; on medium sites it is 60 cm for balsam poplar and black cottonwood and 40 cm for aspen. On drier sites, target annual leader growth for free-growing aspen is 25 cm (M.J. Connor, pers. comm., B.C. Min. For., Prince George, B.C.,1988). Alternative ways to define "free-to-grow", as shown by the Ontario and British Columbia examples, should be a subject of further study.

8 STAND TENDING REQUIREMENTS

8.1 The Problem

Now that aspen is being used commercially, every mixedwood silvicultural practice that has been used to date in northeastern British Columbia needs to be re-evaluated. The silvicultural and economic aspects of stand tending in boreal hardwoods in British Columbia are not well documented. Information on the suitability and response of various sites to stand tending, and on methods and timing of various stand improvement techniques, must be gathered. In mixedwood stands that are to be harvested for hardwoods, a key concern is how to remove the hardwoods without damaging the understorey spruce.

8.2 Information from the Literature

This section deals with stand tending in pure hardwood (rather than mixedwood) stands, and focusses on information from study locations that were considered to have the greatest ecological affinities with northeastern British Columbia mixedwood and hardwood ecosystems. Guidelines for stand tending in more distant aspen-dominated ecosystems in the Lake States, the Rocky Mountain region of western United States, and Alaska may be appropriate to consult in some cases. They include:

Graham *et al.* 1963; Perala 1972, 1977; USDA Forest Service 1972; DeByle 1976; Perala and Russell 1983; Shepperd and Engelby 1983; and Zasada and Argyle 1983.

8.2.1 Protecting understorey spruce during aspen removal

In those mixedwood stands where conifer removal remains as the main goal, the residual hardwoods are generally considered to be an obstacle for harvest operations, site preparation, and coniferous regeneration activities. Stand tending requirements in this context were reviewed in a previous report (Revel 1983). In the Fort Nelson region, where there are widespread stands of aspen with good advance regeneration of white spruce, there is a strong interest in preserving the spruce regeneration.

Techniques developed by Froning (1980) to reduce damage to understorey white spruce by planned logging of aspen overstorey may be applicable to northeastern British Columbia. In an experimental area near Hudson Bay, Saskatchewan, 56% of the spruce were damaged in a 60-ha area where the logging contractor was given no guidance on methods to reduce damage to spruce. In contrast, in a nearby 16-ha trial area, where logging was planned and the skidder operator was supervised, there was only 12% damage and 7% total destruction of the white spruce understorey after skidding. This degree of protection to the spruce was achieved in the following way. Surveys were conducted before logging to map the spruce understorey. Major skid trails were flagged, based on the stocking of white spruce, with sufficient flexibility to take advantage of gaps in the understorey. Bunching of aspen logs was done in the directon of skidding. Over 75% of the hardwoods were logged; those remaining were often in dense clumps of spruce which would not have been removed under normal conditions. Other aspen was left standing to serve as "guard trees" for the deflection of skidded material around curves or turning points.

According to Froning (1980), vulnerability of spruce to windthrow is high when dense mixed stands are opened. Leaving some hardwoods reduces wind damage to critically exposed spruce trees, an important consideration in the development of silvicultural guidelines for spruce release from aspen (Johnson 1986). Froning (1980) also warned against logging hardwoods when temperatures are very low as skidding whole trees under those conditions increases mortality and damage to understorey spruce.

A deterrent to the widespread use of the methods developed by Froning (1980) is the time and cost required for planning and supervising the logging and skidding operations. An alternative approach, which requires less supervision, is in use by Pelican Spruce Mills Ltd. near Edson, Alberta, where overstorey aspen is being harvested from mixedwood stands. Damage or loss of understorey spruce is minimized by the movement of a mechanical harvester into the stand along parallel swaths. Within reach of the boom, aspen are removed from both sides of the swath and placed lengthwise along the track created by the mechanical harvester as it backs into the stand. Trees are skidded along this same track. The result is a swath up to 6 m wide, in which there is substantial damage and loss of understorey spruce, but between each disturbed swath there is a 9-12 m wide area in which aspen has been removed by the mechanical harvester with little or no disturbance to spruce (N. Denney, pers. comm., Pelican Spruce Mills Ltd., Edson, Alta.,1988).

8.2.2 Releasing spruce from aspen competition

There is considerable literature on stand tending techniques to release spruce from aspen competition. In his review Johnson (1986) concluded:

- Present information suggests at least a 35% increase in merchantable white spruce volume following appropriate release from aspen overstorey.
- On a purely silvicultural basis, release of white spruce from aspen and shrubs is a viable forest management option.

- The greatest growth response for released white spruce appears to be 20- to 40-year-old age class.
- White spruce over 75 years of age does not respond well to release from aspen overstorey.
- Gross total yields of well-stocked mixedwood stands are not changed significantly by release treatments. However, growth is concentrated on the conifers, usually the preferred species.
- Rotation age of spruce in pure stands is 30-40 years less than in mixedwood stands, due to the aspen competition in the latter.
- White spruce understoreys must be at least 2.5 m tall to stay ahead of new aspen sucker growth and shrub competition subsequent to a single manual release treatment.
- If white spruce seedlings are less than 2.5 m tall at the time of release they will likely require at least one additional release treatment.
- In general, above a minimum treatment area size, aerial application of herbicides is the least expensive release method, but there are social and environmental problems associated with it.
- Manual release programs may be viable options in troubled economic times, where herbicide use has not gained acceptance, or on small areas with good access (Johnson 1986).

Other recent reports that contain information on stand tending in boreal mixedwood stands include: *Boreal Mixedwood Symposium* (Whitney and McClain 1981); *Broadleaves in Boreal Silviculture: An Obstacle or an Asset?* (Hagglund and Peterson 1985); *Management of the Boreal Forest* (Resource Development Council Education Foundation, Inc. 1987);*Mixedwood Management Information Compendium* (Canadian Forestry Service 1988); *Management and Utilization of Northern Mixedwoods* (Samoil 1988); and a recent review of boreal mixedwood forest management challenges prepared by Peterson *et al.* (1988a).

8.2.3 Silviculture for pure aspen stands

In contrast to the complex ecological and silvicultural questions raised by interspecific competition in mixedwood stands, the literature dealing with pure aspen stands gives the impression that a "hands-off" approach may be the most appropriate form of silviculture. For example, the *Silvicultural Guide to the Aspen Working Group in Ontario* sums up a commonly held viewpoint about stand tending in aspen:

> No cleaning, thinning or pruning of young aspen stands is recommended. (Heeney *et al.* 1980).

This advice was modified slightly in the 1988 version of Ontario's silvicultural guide (Davison *et al.* 1988) with the words:

> Intensive practices, such as thinning, although not operationally practiced in Ontario, may be used in immature aspen stands to accelerate the diameter growth and thus improve sawlog and veneer production--when the markets and economics warrant it.

A similar viewpoint is evident in the United States aspen literature, as indicated by the advice of Perala (1972), cited below from DeByle (1976):

> Little care is needed once a fully stocked, rapidly growing, even-aged aspen stand has been established. If too dense, the stand will thin itself with little loss in growth due to competition.

Jones (1976) added to this consensus as follows:

> I do not recommend commercial or precommercial thinning. There may be situations where thinning is desirable--where it improves stand values and is safe. If so, we need to define situations and methods before we launch any thinning programs.

8.2.4 The role of thinning in aspen stands

The above quotation from Davison *et al.* (1988) identifies a key point brought out by literature on the pros and cons of thinning in aspen: **If the goal is to accelerate diameter growth to improve the value of aspen for sawlog and veneer production, then thinning should be considered; if the goal is to increase total biomass yield, then thinning is a more questionable expenditure.** Work by Steneker (1964, 1969, 1974) in the prairie provinces and by Zasada (1952) and Zehngraff (1949) in the Lake States gives ample evidence that thinning does stimulate the diameter increment of all tree sizes. Steneker (1976) recommended that thinning be considered, **on good sites only**, when the objective is to produce large trees for lumber or peeler logs in a short period of time. Other authors who have presented arguments or criteria for thinning in aspen include: Graham *et al.* (1963); Steneker and Jarvis (1966); Jarvis (1968); Schlaegel (1972); Brinkman and Roe (1975); Perala (1977, 1978); Weingartner (1981); and Jones and Shepperd (1985). The exceptionally high stem density of many aspen stands of sucker origin has also spurred interest in thinning (Jones 1976), though there are other reasons for doing so as well. For example, Navratil (1987) suggested that thinning could be used to remove decay-prone aspen trees and to manipulate clonal composition.

Steneker (1974) felt that thinning would be unjustified if the anticipated end product from aspen or poplar were fibre or pulp. However, in his guide to the silvicultural management of aspen, he indicated that for fibre production, thinning to salvage mortality may be justifiable on good and intermediate sites but not on poor sites. It is noteworthy that, with increased stem diameters not being critical for the desired product, the greatest basal area and greatest total volume occurred on unthinned control plots described by Steneker (1964). Therefore, if an aspen manager's goal is to maximize total fibre yield, with no concern to produce large trees for a specific product that needs them, there is little reason to consider thinning in this species. As reported at the 1988 meeting of the Poplar Council of Canada (I.E. Bella, pers. comm., Northern Forestry Centre, Edmonton, Alta.,1988), there is evidence that the incidence of *Hypoxylon* infection is greater in thinned than in unthinned stands, especially if thinning is done after trees are 10-15 m tall.

Many other researchers, in addition to those cited above, have recommended against thinning in aspen (Bickerstaff 1946; Heinselman 1954; Anderson and Anderson 1968; Sorensen 1968; Schlaegel and Ringold 1971; Schlaegel 1972; Hocker 1982; Walters *et al.* 1982; Jones and Shepperd 1985). Ultimately, however, aspen managers must use local criteria to determine whether thinning is justified.

8.2.5 The role of fertilization

Information on the effects of fertilization in aspen stands (Van Cleve 1973; Coyne and Van Cleve 1977; Parkerson 1977; Czapowskyj and Safford 1979; Van Cleve and Oliver 1982) is limited. In Canada, interprovincial forest fertilization trials described by Weetman *et al.* (1987) revealed that there were notable 5-year responses to fertilization in a 35-year-old aspen stand in Saskatchewan. The results can be summarized as follows:

Initial total volume in stand:	145 m^3/ha
5-year increment:	
in control area	33.5 m^3/ha
N at 112 kg/ha	35.6 m^3/ha
N at 224 kg/ha	49.6 m^3/ha
N at 224 kg/ha and P at 112 kg/ha	50.1 m^3/ha
N at 224 kg/ha and K at 112 kg/ha	59.4 m^3/ha
N at 224 kg/ha and P and K at 112 kg/ha	70.8 m^3/ha

These responses translate into increased yields ranging from an extra 6% of 5-year increment when N only was added at 112 kg/ha, to an extra 111% of 5-year increment when N at 224 kg/ha and P and K at 112 kg/ha were added. Other fertilization trials on aspen in Alaska (Van Cleve 1973; Van Cleve and Moore 1978; Van Cleve and Oliver 1982; Chapin *et al.* 1986) show substantial increases in aspen production, especially in response to increased nitrogen.

Steneker (1976) suggested that in the mixedwood section, with a short growing season, fertilization would not greatly improve growth. Furthermore, because productive aspen sites are characterized by an abundant cover of understorey vegetation, the potential benefits of fertilization may be lost to uptake by ground vegetation. He suggested that control of understorey vegetation would be a greater stimulus to aspen growth than fertilization would be. It is significant that the understoreys of many aspen stands are characterized by the presence of *Alnus, Shepherdia*, and several legumes, all of which are capable of nitrogen-fixation. Several unanswered questions remain about nutrition management in aspen stands (P. Comeau, pers. comm., B.C. Min. For., Victoria, B.C., 1988): How will nutrient availability change as management and intensity of utilization change? How will increased utilization of hardwoods influence the need for fertilizers? How could this be predicted or evaluated?

8.2.6 Short-rotation management

There is considerable literature on short-rotation management of aspen and black cottonwood (Bella and Jarvis 1967; Einspahr and Benson 1968; Person *et al.* 1971; Heilman *et al.* 1972; Berry 1973; Smith and DeBell 1973; Ek and Brodie 1975; Berry and Stiell 1978; Ohmann *et al.* 1978; Perala 1979; Stiell and Berry 1986). However, because of the assumption in this review that priority would be given in British Columbia to harvesting existing stands, stand tending for short-rotation management of aspen was not reviewed here.

8.2.7 Pruning

In many forestry operations, pruning is an important stand tending activity, but it is not recommended for aspen stands because this species self-prunes quite effectively. The Manager's Handbook for High-value Hardwoods by Berry (1982) points out that pruning may inadvertently create entry courts for decay-causing fungi. Therefore, in species such as aspen or balsam poplar, where minimizing future decay losses is an important objective, pruning becomes a questionable stand tending activity. As well, because it involves a financial outlay, it should be limited to trees that are expected to escape decay.

8.2.8 Management to reduce decay losses

The relative proportions of stump sprouts and root suckers in aspen or balsam poplar stands may be significant for stand management to reduce decay losses. In stands of hardwoods that exhibit strongly clumped sprouts around cut stems, there should be emphasis on reducing the number of

such stump sprouts because the stump serves as an infection court for decay-causing fungi (Berry 1982). There could be even greater risks of decay in aspen if the regenerating stand contains a relatively high proportion of stump sprouts, which would be the case if aspen were harvested on short rotations of 25 years or less. In stands older than approximately 25 years, root suckers predominate over stump sprouts (Heeney *et al.* 1980).

Some of the present anxiety about aspen use is based on a belief that much of the present volume will not be available because of rapid losses from decay after 80 years of age. Related concerns are that the wood will be costly to deliver because considerable amounts of cull would be included in the material harvested and hauled. Even worse, is the concern that future volumes will not yield marketable products, again because of decay and stand break-up (Dempster 1987).

Some short-term approaches for managing the decay and resource-quality problem include shorter rotations, integrated use, and new uses for low-grade raw materials. A longer-term approach might be the application of genetics. In the meantime, aspen management involves difficult decisions that are often influenced by the marketplace. For example, there are existing hardwood volumes that cannot be used with existing technology (Dempster 1987), usually because of poor wood quality. Just as aspen managers cannot ignore the realities of aspen age-class distributions, nor can they ignore that wood quality criteria dictate the marketability of many products. The latter point is well documented by Kennedy (1974) and Wengert (1976). Some analysts have suggested that only a portion of the allowable annual cut is likely to be successfully used in a competitive marketplace. There is, therefore, a need to define which aspen stands can be used with the least investment risk and the best chance of success (Barr 1987; Dempster 1987). This raises other questions: What is to be done with aspen stands that are not used? What options are available for recycling old aspen stands that cannot be used, including not only forestry options but possible wildlife or agricultural land uses?

At the Aspen Quality Workshop (Canadian Forestry Service and Alberta Forest Service 1987), Navratil urged that greater attention be given to procedures for growing aspen stands of higher quality and lower volume of defects. He referred to Russian information, without citing specific references, which indicated that thinning strategies can be effective in decreasing the proportion of stand volume that is rotted from *Fomes igniarius*. Sanitary thinnings carried out to reduce the incidence of *Fomes* rot can also serve to control clonal composition, provided the clones are well intermingled.

8.2.9 The need for demonstration areas

It is not too early to establish some demonstration areas in northeastern British Columbia to provide guidance on decay management in aspen. For example, the guidelines prepared by Berry (1982) suggest that the incidence of decay may be lessened by felling or girdling any trees with external conks during stand improvement operations. The conks would remain for several years as a source of spores even after such trees are felled or girdled, but this step would at least reduce the duration of such infection sources by a number of years.

8.3 Interim Solutions Based on Available Information

Several interim recommendations for hardwood-related stand tending have already been put forward by Revel *et al.* (1986). For the Fort Nelson TSA, the recommendation is to leave residual aspen and poplar standing when conifers are harvested. Aside from saving the cost of felling, this practice would provide shade for planted spruce and reduce the grass competition that exists in totally clearcut areas. Unlike aspen and balsam poplar, birch residuals are recommended for felling during conifer removal to reduce the chance of dense birch re-invasion.

For the Fort St. John and Dawson Creek TSA's, Revel *et al.* (1986) recommended partial or complete removal of the hardwood canopy in areas where conifers are harvested. This removal of hardwood overstorey can be done by a pre-harvest "hack and squirt" application of Roundup® or by felling. The task

force suggested that felling residual aspen should occur in late May or June, during the half-leaf stage, to minimize suckering.

8.3.1 Focus on fibre, pulp and chip products

It was assumed for the present review that use of the aspen resource for fibre, pulp, and chip products would be dominant in northeastern British Columbia for the foreseeable future. Birch is manufactured into sills, frames, and moulding. In addition, some aspen and poplar stems are used as peeler logs, and various hardwood raw materials are shipped to Pacific Rim countries for specialty products (Grant 1980). However, it was assumed that such needs for larger stem sizes could be met by harvest of existing mature stands, and that young or immature boreal hardwood stands would not need to be intensively managed and thinned to produce the larger stem sizes required for such specialty products. Therefore, thinning aspen to enhance diameter increment is not now considered to be a high priority activity on an operational scale in northeastern British Columbia.

8.3.2 The context for thinning trials

Despite the reservations described above, it was noted that Revel *et al.* (1986) recommended thinning trials at age 10-15 "to determine if it would increase tree size and yields of aspen," particularly on high quality sites close to processing facilities. If there is interest in proceeding with these suggested thinning trials, it is recommended that they be established at locations where they can complement aspen growth and yield studies and other stand density studies (L. Herring, pers. comm., B.C. Min. For., Prince George, B.C., 1988). Ideally, such trials should be stratified according to recognized seral aspen ecosystems such as described by DeLong (1988). If northeastern British Columbia thinning trials are initiated in very young aspen stands, it should be noted that the expression of dominance is unstable during the first 2 or 3 years. Thus, the best potential crop trees could probably not be selected for thinning or release until about age 4. Such age-related differences have been demonstrated in the Lake States where thinning in 1-year-old aspen (Sorensen 1968) produced poor growth response compared with thinning in a 13-year-old stand (Perala 1978).

8.3.3 A move to shorter rotations

Because there are large volumes of mature hardwoods available for harvest on public lands in northeastern British Columbia, it is difficult to encourage methods for reducing decay losses in future stands. However, this objective was mentioned in Section 8.2 in the context of owners of private woodlots who may look to the quality and quantity of the next crop with a shorter time horizon than would public land administrators. Furthermore, the potential for future decay losses will be a concern for industries that have sources of hardwoods close to the processing plants.

8.3.4 A new attitude towards NSR and NCBr lands

In northeastern British Columbia, the main change needed will be a shift from rehabilitation programs that have been attempting to convert NSR and NCBr lands to conifers. As pointed out by Revel *et al.* (1986), many of these areas already support thrifty, young, fully-stocked aspen stands. The task force recommendation that such NSR and NCBr lands be allowed to develop to aspen stands should be followed. Any commitments to establish spruce on lands in the Dawson Creek or Fort St. John TSA's should focus on recently harvested areas where hardwood competition is not yet well established.

8.4 Suggested Follow-up

If there is local knowledge that certain northeastern British Columbia aspen stands are not adequately self-thinning by age 10, follow-up documentation of such stands should be collected. In view of the limited evidence in the literature that thinning would be operationally important for fibre-oriented aspen management, there should also be documentation of the ecological, stand, and site circumstances where thinning trials would have the greatest justification. This could presumably include definition of hardwood stands and sites that have the best potential for lumber or veneer production.

Fertilization responses are not widely known for aspen stands and the trials done to date in Alaska and Saskatchewan should be repeated for northeastern British Columbia hardwood-dominated ecosystems.

Several ecological studies have already been recommended by Revel *et al.* (1986) to clarify the role of residual overstorey hardwoods in promoting spruce regeneration in areas where all mature spruce trees have been harvested. Revel *et al.* (1986) hypothesized that spruce regeneration is more dependent on shade from overstorey trees in the Fort Nelson region than is the case further south in northeastern British Columbia. It is recommended that the work suggested by Revel *et al.* (1986) be initiated in the Fort Nelson region, because this subject is not well documented in mixedwood literature from elsewhere.

9 GROWTH PROJECTIONS

9.1 The Problem

Although considerable data are available, existing growth curves for aspen, balsam poplar, and black cottonwood should be confirmed in northeastern British Columbia. Once growth curves are confirmed or amended, and present hardwood age-class data are refined, it will be possible to proceed with more detailed modelling of hardwood and mixedwood stands, based on local mensurational data.

Improved growth projections are important because the increasing use of aspen is raising new questions about calculating allowable annual cut. For example, foresters faced with a decision of what to do with a harvestable aspen stand that contains an understorey of spruce have several choices. One is to remove the aspen, with considerable risk of damage to the spruce regeneration. Another is to harvest the aspen and be prepared to replant spruce. A third is to simply leave the aspen and wait for up to 80 years to harvest the spruce. Without good growth data the right decision is difficult to make.

Growth projections are hampered by uncertainty about aspen stand characteristics after approximately age 60. Sample plots established by the Ministry of Forests in pure aspen types (C. DeLong, pers. comm., B.C. Min. For., Prince George, B.C., 1988) revealed that on some mesic and subhygric sites there are two different patterns of diameter distribution and stand development after age 60. Some stands break up, allowing new stems to come in and a multi-aged stand to develop. Other stands remain intact and continue to add increments to at least age 90. Field observations have not yet revealed ecological or stand history reasons for these differences.

9.2 Information from the Literature

Growth and yield literature from boreal hardwood or boreal mixedwood stands in areas outside northeastern British Columbia must be interpreted with caution because productivity is strongly influenced by regional and local ecological conditions. Generally, there is no substitute for local mensurational data.

9.2.1 Key data sources from other regions

Productivity estimates from other regions are available in reports by: MacLeod (1950)[4]; MacLeod and Blyth (1955); Plonski (1956, 1974); Johnson (1957); Kirby *et al.* (1957); Kirby (1962); Gregory and Haack (1965); Bella (1975); Johnstone (1977); Bickerstaff *et al.* (1981); Horton (1981a,b); Smith (1981); Carmean (1985); and Packee (1985). These growth and yield reports were not summarized for this review because of uncertainty about their applicability to the study area. It is useful, however, to highlight several references that provide estimates of culmination of mean annual increment.

Information summarized by Heeney *et al.* (1980), based largely on data from Plonski (1956, 1974), indicates that, in Ontario, culmination of mean annual increment (gross merchantable volume) occurs at 55 years for aspen in the best sites, 60 years in medium sites, and 65 years in poor sites. Based on biomass rather than volume, Horton (1981b) estimated that maximum MAI and CAI occurred between 45 and 60 years in aspen in Ontario's Boreal Forest Region. At a rotation age of 60 years, the best aspen sites in Ontario produce 330 m^3/ha and medium aspen sites, at a rotation age of 65 years, produce 280 m^3/ha. Perala (1973) developed a prediction model from young stand data which showed a culmination of biomass MAI at approximately 26 years for aspen in the Lake States. Biomass yield tables for aspen stands to 44 years of age in Alberta and Saskatchewan showed culmination of MAI at 25-30 years (Bella and DeFranceschi 1980). Average annual biomass accumulation of 5-10 t/ha per year is possible in aspen stands (Hambly 1985).

The gross merchantable volume of aspen in Ontario compares well with its associated species, as shown by the following information assembled by Hambly (1985), using data from Plonski (1974).

Species	Age at rotation	Gross merchantable volume (m^3/ha) at rotation
Aspen	55	300
Jack pine	45	180
Spruce	105	250
White birch	60	170
Tolerant hardwoods	90	220
White pine	65	350
Red pine	45	260

Hambly (1985) pointed out that calculating rotation age based on biomass could shorten the rotation by 10-15 years, compared to calculating it on a volume basis. A sample biomass yield table for productivity class I in the Boreal Forest Region of Ontario is reproduced from Horton (1981b) in Table 9.

9.2.2 Growth projections on a biomass basis

Hambly (1985) recorded biomass values (t/ha dry weight) for aspen stands in study sites that ranged from Alberta southeast to Ontario and the Lake States. In the sampled stands, total stem, bark, and branch standing crop for mature stands varied from a low of 7 t/ha to a high of 810 t/ha. Most values fell in the range of 40-300 t/ha. The very low value (7 t/ha) was a severely understocked stand described by James and Smith (1977) in southern Ontario. The extremely high value of 810 t/ha was from one specific clone on a moist clay loam site that was excellent for aspen growth in the Blue Ridge area of Alberta (Lehn and Higginbotham 1982).

4 W.K.MacLeod.1950. Growth, development and yield of spruce-popular stands in northern Alberta. Dep. Resources and Dev. For. Branch. Unpubl. manuscript.

TABLE 9. Sample biomass yield table for aspen on productivity class 1 in the Boreal Forest Region of Ontario (Source: Horton 1981b)

Age (yrs)	Height (m) Mean	Height (m) Dominant	Mean Dbh(cm)	Number trees/ha	Basal area m^2/ha	Ovendry mass (t/ha) Whole tree	Ovendry mass (t/ha) Stemwood	MAI (t/ha) Whole tree	CAI (t/ha) Whole tree
10	5.8	9.9	3.7	11 618	12.4	19	14	1.8	–
15	8.5	12.4	5.8	6 717	17.6	39	28	2.6	4.0
20	11.1	14.7	8.0	4 404	22.2	64	46	3.2	5.0
25	13.6	17.0	10.3	3 122	26.2	92	67	3.7	5.7
30	15.8	19.2	12.6	2 370	29.6	121	88	4.0	5.8
35	18.0	21.2	14.9	1 859	32.5	150	110	4.3	6.0
40	20.1	23.1	17.4	1 485	35.1	182	133	4.6	6.3
45	21.9	24.7	19.5	1 245	37.1	210	153	4.7	5.5
50	23.5	26.1	21.6	1 061	38.9	236	172	4.7	5.2
55	25.1	27.4	23.6	922	40.3	261	190	4.7	5.0
60	26.2	28.5	25.2	828	41.4	280	204	4.7	3.9
65	27.2	29.4	26.5	762	42.1	295	215	4.5	3.1
70	28.0	30.2	27.7	710	42.8	309	225	4.4	2.8
75	28.7	30.8	28.7	668	43.3	321	234	4.3	2.3
80	29.3	31.3	29.6	635	43.7	330	240	4.1	1.9
85	29.8	31.7	30.3	610	44.0	338	246	4.0	1.6
90	30.2	32.1	30.8	592	44.2	344	250	3.8	1.1

The latter reference is of interest for growth projections because it demonstrates the differences in productivity associated with clonal variability. At both the foothills study site near Nordegg, Alberta, and the boreal site near Blue Ridge, there was a large amount of clonal variability in biomass production. Lehn and Higginbotham (1982) calculated that the expected gain in bole biomass would be as much as 9.2 kg per stem if only the best clone was measured instead of all six in the sample area. At Blue Ridge, the best clone had a mean bole weight 43.9 kg greater than the mean bole biomass of six clones in the study area. Based on mean numbers of stems per hectare and the maximum potential gains mentioned above, biomass at 85 years could be increased by 17 885 kg/ha at Nordegg and 58 124 kg/ha at Blue Ridge if only the best clone was involved.

9.2.3 Modelling of aspen growth

To model aspen growth, several approaches have been described: Bella (1970, 1972); Grabowski (1981); Grabowski *et al.* (1981); and Holdaway and Brand (1983). Bella (1970, 1972) developed a yield forecasting model that used periodic height and dbh increment to sum tree data for a unit area from early growth to harvest. The model was tested for simulation of aspen stand growth in natural, undisturbed stands of average or below average density, and was calibrated with data from an above average site in Saskatchewan. Grabowski (1981) and Grabowski *et al.* (1981) incorporated a larger, more diverse aspen data base than Bella's Saskatchewan data and modelled individual tree growth rather than stand growth. Grabowski *et al.* (1981) also added a mortality function that was sensitive to stand conditions, but predictions were difficult because of the highly variable mortality rates exhibited by different aspen stands. Shields and Bockheim (1981) investigated stand break-up in Ontario and the Lake States by comparing stand basal area at a given age to the maximum basal area, which is achieved at approximately age 55 years in all site classes in that region. Maximum basal area for the most productive site class was approximately 35 m^2/ha.

Several investigators have noted the difficulties of projecting growth in young stands. Heeney *et al.* (1980) observed that relationships between aspen growth and site characteristics are less evident

in stands 40 years or younger than they are in older stands. For this reason, it is important to identify ecological and other criteria that could assist the traditional mensurational approaches for growth projections in young stands on sites of varying quality.

9.3 Interim Solutions Based on Available Information

As with improvements to the inventory database (Section 4), refinement of productivity estimates for boreal hardwoods is a long-term program that requires local data. Interim solutions, therefore, are not particularly important. Of more importance are the long-term commitments referred to in Section 9.4.

9.4 Suggested Follow-up

The additional analyses required to refine growth projections for boreal hardwoods are an integral part of work planned or already under way by the Inventory Branch. Successive refinements of site index equations and curves, such as those originally prepared by Hegyi *et al.* (1979) for aspen, balsam poplar, and black cottonwood, is a long-term activity.

Integrating mensurational data collection and ecological site descriptions is a high priority. Work planned by the Ministry of Forests (C. DeLong, pers. comm., B.C. Min. For., Prince George, B.C.,1988), focussing on simultaneous inventory and ecological classification of hardwood stands, will contribute information that can be used to improve growth projections. A specific goal should be the production of ecologically stratified growth and yield estimates for both hardwood and mixedwood stands. There are excellent prototypes of such estimates for coniferous ecosystems elsewhere in British Columbia (Klinka *et al.* 1981). For boreal mixedwood ecosystems, the work by Corns and Annas (1986) for west-central Alberta and by Kabzems *et al.* (1986) for Saskatchewan can serve as models for similar work in northeastern British Columbia.

To improve growth projections for hardwoods, more data should also be collected in stands that have been identified by the Ministry of Forests as vigorous beyond age 60 (C. DeLong, pers. comm., B.C. Min. For., Prince George, B.C., 1988). Mature stands that maintain their integrity between ages 60 and 90 provide some of the most interesting management possibilities in northeastern British Columbia.

10 REFORESTATION REQUIREMENTS FOR PURE ASPEN AND MIXEDWOOD TYPES

10.1 The Problem

The working group considered reforestation requirements to be a low priority in pure hardwood stands, but a medium priority in mixedwood stands. The key concern in pure aspen stands is the relative lack of local knowledge about aspen regeneration response after different methods and timings of harvest activities. The key concern in mixedwood stands – in which selective removal of conifers is still the main activity – is the unpredictability of aspen sucker density after conifer removal.

10.2 Information from the Literature

This section focusses on stand and site conditions, management activities, and other events that promote or hinder establishment of aspen suckers or seedlings. The requirements for spruce seedling establishment in mixedwood stands is a separate subject beyond the scope of this review.

10.2.1 Aspen of seedling origin

Most of the aspen literature emphasizes that conditions for natural seedling establishment are so critical that stands of seedling origin are relatively infrequent. However, such stands have been documented on various surfaces: drained sedimentary peat in Minnesota (Nielsen and Moyle 1941); ashes of burned-out peat, following drainage in Wisconsin (Strothmann and Zasada 1962); volcanic

cinder cones in Idaho (Eggler 1941); landslides in New England (Flaccus 1959); nursery beds intended for other species (Graham *et al.* 1963); mine tailings (Williams and Johnston 1984); a variety of harvested or burned-over lands that were formerly occupied by other forest types in the Lake States (Kittredge and Gevorkiantz 1929); and regeneration survey plots in western Alberta (J. Fochler, pers. comm., Alta. For. Serv., Spruce Grove, Alta., 1988)

The best chance for aspen seed germination and survival is on an alluvial or humus seedbed with moderate temperatures, a reliable and continuous moisture supply during seed germination, good drainage, and little competition from other vegetation (Steneker 1976). If the required seedbed conditions are present in the 2 or 3 weeks during which aspen seeds retain their viability, then seedling production can be prolific. Aspen seed supply is not a limiting factor. It is plentiful most years and very abundant every 4 or 5 years (Kittredge and Gevorkiantz 1929; Horton and Maini 1964). Zasada *et al.* (1977) have noted that seed regeneration of aspen is potentially more important in Alaska than in more southerly parts of its range, because of the occurrence of relatively cold soil conditions and the reduced suckering capacity of aspen at low temperatures.

10.2.2 Aspen of sucker and stump sprout origin

Most attention has been given to aspen regeneration from root suckers and stump sprouts. Unlike in black cottonwood or balsam poplars, the rootability of stem cuttings is extremely poor in aspen (Maini 1968). Although it reproduces prolifically from suckering, it does not exhibit the variety of vegetative reproduction mechanisms shown by balsam poplar, which can reproduce under natural conditions from stump sprouts, root suckers, and buried branches (Zasada *et al.* 1981). Most regeneration in aspen is by root suckers, although stump sprouts and root collar sprouts occur if the harvested trees are relatively young (Heeney *et al.* 1980).

Hambly (1985) listed the following factors as controls over aspen suckering: growth regulators, particularly auxins and cytokinins (Farmer 1962; Steneker 1972; Schier 1976); root carbohydrate reserves (Schier and Zasada 1973; Schier 1976); root size (Kemperman 1978); the inherent ability of each individual clone to sucker (Maini 1967); soil temperature (Horton and Maini 1964; Maini and Horton 1966; Gifford 1967; Perala 1974; Steneker 1974; Schier 1976); root depth (Horton and Maini 1964); and soil moisture levels (Maini and Horton 1964, 1966). The amount of suckering also depends on the degree of stand disturbance. Stand age does not affect suckering ability, provided the stand is not breaking up because of decay (Steneker 1976).

Most aspen suckers originate along horizontal lateral roots that have diameters between 0.5 and 2.5 cm. These roots occur predominantly in the upper 60 cm of soil and most suckering occurs where the roots are from 4 to 12 cm below the surface (Horton and Maini 1964). Most suckers are formed during the first growing season after a major disturbance such as fire or harvesting, although others originate during the second or third growing seasons (Sandberg and Schneider 1953; Heeney *et al.* 1980). Suckering ability may be as much as 20 times greater in some aspen clones than in others (Farmer 1962; Boekhoven 1964; Garrett and Zahner 1964). However, the main control over suckering is insolation-induced temperature increase. Maini and Horton (1963, 1964) concluded that the soil temperature increase that results from logging – rather than the actual cutting of aspen trees – is the most critical requirement for sucker stimulation.

10.2.3 Suckering in relation to harvest methods

Harvesting aspen during the dormant season generally results in maximum aspen suckering during the next growing season, but after 2 or 3 years the effect of cutting season is negligible. Therefore, as long as the present stand is healthy and well stocked, clearcutting can be carried out at any time with reasonable assurance that a sucker stand will follow (Steneker 1976). This leaves considerable flexibility in harvest scheduling for aspen stands. Selecting season of harvest may, however, be based on other criteria. For example, winter logging produces more uniform and less dense regeneration, facilitates harvest, and prevents soil compaction on wetter soils with clay components. In contrast, summer logging may be more destructive to shrub cover than is winter

logging, thereby lessening competition for aspen suckers (Bella 1986). In the Lake States, subsequent survival and growth of suckers can be seriously reduced if there is residual shading because aspen requires full sunlight to develop (Zehngraff 1947; Stoeckeler and Macon 1956; Farmer 1963; Perala, 1972.)

A complete clearcut without burning is still the best way to regenerate aspen stands. However, if burning is used to reduce overstorey shading or to increase soil temperatures, then the stands should be burned during the first dormant season following harvest, and preferably before substantial suckering takes place. This procedure would minimize growth loss caused by the re-initiation of suckering. Assuming there is good drying weather, aspen slash from summer harvesting can be ready to burn in the fall of that year or during the following spring (Perala 1974).

10.2.4 The silvicultural importance of aspen root systems

Understanding sucker dynamics requires an understanding of clonal root dynamics. Silvicultural activities in aspen stands should recognize that death of an aspen stem does not necessarily mean death of the underlying roots. There are records of aspen stems that have died and rotted away from parent roots that remained alive, still serving the clonal group (Gifford 1966).

Aspen managers should recognize that a substantial root system may persist even when successional or other factors severely limit the above-ground standing crop of aspen. The tenacity and longevity of the root systems of aspen clones were shown in the predominantly coniferous forest types of the lower foothills in Alberta, where Horton (1956) found aspen suckers in almost every forest stand regardless of age, density, or species composition. This suggests that, in some areas, aspen roots may persist in the absence of canopy aspen, nurtured only by transient suckers beneath the coniferous canopy (DeByle and Winokur 1985). Such root systems, however, would not necessarily be expected to produce a dense new crop of suckers immediately if the coniferous overstorey were removed, because poorly stocked aspen stands tend to produce few suckers.

10.2.5 Early growth of suckers

Early growth after forest fires or clearcutting is extremely rapid in aspen and balsam poplar (as it is in alder and willow species), giving these species an advantage over trees that regenerate from seeds, as well as an advantage over competing grasses and herbs (Hiratsuka and Loman 1984). In locations where aspen occurs in association with other hardwoods, prescribed fire can effectively control residual hardwood overstories that are detrimental to aspen sucker growth and survival. Although the long-term effect of fire on sucker growth is unknown (Perala 1974), in the short term burning appears to reduce the vigour of resulting aspen suckers, perhaps because of the loss of nitrogen upon burning or because of the heat damage to the shallow sucker-producing parent roots (Horton and Hopkins 1965; Van Cleve 1973; Perala 1974).

10.3 Interim Solutions Based on Available Information

Revel *et al.* (1986) suggested that, except where the intent is to convert aspen stands to spruce, the interim strategy for aspen regeneration should be to clearcut, and to set a goal of 5000 well-distributed aspen trees per hectare. Steps to take if there is inadequate natural regeneration from root suckers have not yet been defined for northeastern British Columbia.

Until more specific hardwood regeneration problems are defined by Regional and District staff, it is premature to suggest any additional interim steps. Furthermore, as outlined in Section 10.4, a more focussed review is needed of the available information on hardwood regeneration requirements, specifically in response to questions or hypotheses derived from local field observations and in relation to local ecological conditions.

10.4 Suggested Follow-up

One of the research needs identified by the Ministry of Forests (J. Revel, pers. comm., B.C. Min. For., Prince George, B.C., 1988) is evaluation of seedlings versus suckering for hardwood stand establishment. There are some indications that aspen seedling establishment may be more important in relatively cold northern soils than is generally believed. For example, in the Fort Nelson region, the relatively colder soils are believed to be a reason for less vigorous suckering after logging than is observed further south. In addition to the inherently colder soils, the overall greater thickness of the forest floor in more northerly soils adds an insulative cover to aspen roots after canopy removal, and hence greater inhibition of sucker formation (J. Revel, pers. comm., B.C. Min. For., Prince George, B.C., 1988). Additional field studies to quantify these relationships should be undertaken.

The sucker-related research recommended in Appendix F of the task force report (Revel *et al.* 1986) should proceed. This includes: identifying and assessing the effect of pathogens on suckers, with emphasis on pathogens derived from slash and stumps left after clearcutting; assessing competition between native grasses and young aspen suckers; and assessing the effect and role of controlled grazing on aspen regeneration.

The subject of reforestation requirements for pure boreal hardwood stands and boreal mixedwood stands requires considerably more research to relate existing information to specific local questions and to the specific sites and ecological conditions in northeastern British Columbia.

11 SLASH DISPOSAL

11.1 The Problem

The working group suggested that the current Ministry of Forests policy of full-tree skidding, with disposal of debris at landings, raised questions for harvesting operations involving hardwood stands. The influence of slash on subsequent aspen suckering is one concern, although the potential contributions of branches and bark to nutrient status of the harvest site was also questioned. In addition, the fire, insect, and disease consequences of removing all harvested material to landings are not well documented for northeastern British Columbia. The soil compaction that takes place as a result of the concentrated activity around landings was identified as a separate concern (Section 13).

11.2 Information from the Literature

11.2.1 Slash-shade relationships

Slash disposal is of interest because, without it, the additional shade created by slash can potentially lower soil surface temperature, which in turn can reduce sucker formation. Bella (1986) reported that following the harvest of aspen stands near Hudson Bay, Saskatchewan, sucker density was greatest where no slash cover occurred. Sucker density generally declined as the amount of slash increased from limbs only, to logs only, to limbs and logs. Average sucker density differed more, both relatively and absolutely, with slash condition after summer cutting than after winter cutting. Slash left by summer logging had the disadvantage of creating more shade than winter slash because of the foliage present. However, this effect appeared to be offset by the fact that summer logging disturbed the ground vegetation and humus more than did winter logging. As a result, areas logged in summer experienced warmer soil temperatures, which are known to promote root suckering (Maini and Horton 1966; Bella and DeFranceschi 1972; Steneker 1974; Bella 1986). The overall density of sucker regeneration at the Hudson Bay study sites, even with slash present, was comparable to that found in fire-origin stands; and the large initial differences in stand density diminished to 30% or less by the time the suckers reached 5 or 6 years old.

Shoup (1968a,1968b, 1970) also found that the general effect of slash on cutover stands of aspen near Hudson Bay, Saskatchewan, was to slightly reduce suckering, although no effect was

found on the level of stocking finally achieved. After four growing seasons from a winter cut of 1965/66 and a 1967 summer cut, there was no appreciable reduction in the number of suckers in density classes up to about 49 000 stems per hectare. There was, however, more natural thinning in stands with sucker densities over 64 000 stems per hectare. The general conclusion is that logging slash may be left on cutover areas without creating aspen regeneration problems, and logging may be done in summer or winter. Winter logging, however, produces more uniform suckering (Bella and DeFranceschi 1972).

11.2.2 Slash management guidelines

Slash management guidelines developed by Steneker (1976) are felt to be relevant for northeastern British Columbia. In general, complete removal of the original stand, together with harvesting methods that knock down much of the understorey vegetation, will ensure a fully stocked stand of suckers--provided the root system of the original aspen stand fully occupied the site. In overmature stands, which are likely to have heavy shrub vegetation, the preferred time for harvesting is during the frost-free dormant season to encourage the destruction of shrub vegetation. Most of the shrub vegetation will be destroyed or uprooted if complete trees are brought to a landing. However, the area may subsequently have to be treated with anchor chains or other equipment that will destroy residual shrubs (Steneker 1976).

On fresh and moist sites, residual slash after clearcutting has not proved to be a significant hindrance to sucker formation and growth. On wet sites, however, slash may keep soil temperatures below the threshold required for suckering. To promote soil warming and soil disturbance on wet sites, the goals should be to maximize destruction of shrubs and to minimize slash. These goals are best met by full-tree harvesting (Steneker 1976).

11.2.3 Nutrient aspects of slash management

The possible nutrient consequences of removing branches and bark from the harvest site are discussed in a rapidly expanding body of knowledge about the influences of harvesting practices on nutrient relationships, although little of it deals with boreal hardwood ecosystems. The literature on nutrient consequences of forest harvesting in boreal mixedwoods (Gordon 1983; Timmer *et al.* 1983) indicates that nutrient losses will be a concern only if rotations become relatively short. When rotations are 60 years or more, the atmospheric or weathering return of the nutrients removed from the site by each harvesting cycle may be substantial. In this context, Gordon (1981) pointed out that not many years are required for nutrient replacement following full-tree harvesting of a mature mixed woodstand at full rotation. For example, in the Nipigon area of Ontario, he estimated that, in mixedwood stands made up of 25% softwood and 75% hardwood (aspen and birch), the number of years required to replace nutrients lost in a single crop removal were as follows: N replaced in 19 years; P in 15 years; K and Ca in 17 years; and Mg in 14 years.

A relatively high proportion of the above-ground nutrient content in hardwood biomass is in the foliage, and this is particularly true for nitrogen. If whole-tree removal of hardwoods occurs during the leafless season, the foliage component of the nutrient pool is not lost to the site. Aspen nutrient data currently being analysed for the Northern Forestry Centre, Forestry Canada, (Peterson *et al.* 1988b), indicate that nutrient losses from aspen harvesting may not be of concern because a high proportion of total site nutrients is contained in the soil and litter rather than in the harvestable tree components.

11.3 Interim Solutions Based on Available Information

The task force suggestion (Revel *et al.* 1986) that the burning of slash should normally be avoided "as it may lead to gross overstocking of young aspen" is difficult to substantiate from the literature, which shows that a pronounced natural thinning seems to be a common feature of aspen stands in their first 5 or 6 years of development (Table 6). The concern over potential overstocking in young aspen stands in northeastern British Columbia does not appear to be warranted.

11.4 Suggested Follow-up

No specific follow-up work is recommended, other than that already suggested by the working group, which would involve District review of current practices that involve full-tree skidding with disposal of debris at landings. Any such review might be aided by the familiarization with methods currently used to harvest aspen by Pelican Spruce Mills Ltd. in Edson, Alberta, where the practice is to carry out all delimbing at road-side landings and then to burn the accumulated slash periodically at each landing site. The advantages and disadvantages of this practice could not be assessed from information available in the literature--making it a high priority subject for research.

12 REGENERATION RESPONSE

12.1 The Problem

Information needs for regeneration in boreal hardwood stands (Section 10) were considered by the working group to be a low priority problem, and they applied the same low priority rating to regeneration response. However, there may be more uncertainty about the response of established hardwood regeneration in the first few years of stand development than there is about the initial establishment of such stands, particularly where conditions are good for suckering. This uncertainty may be partly a result of inadequate use of available information, rather than of any strong evidence that there are serious threats to established young stands of hardwoods.

12.2 Information from the Literature

"Regeneration response" refers to the period following regeneration establishment. For the purposes of this review, the focus is on events in the first 10 years following harvesting, and includes an examination of conditions and events that influence hardwood seedlings or suckers. The examples deal only with aspen because little documentation is available on the other boreal hardwood species.

12.2.1 Early growth of seedling-origin aspen

Not much published information exists on growth rates of aspen seedlings, but it is known that, compared to suckers, seedlings grow relatively slowly for the first 2 or 3 years (Heeney *et al.* 1980). First-year height growth is generally less than 15 cm and 2nd-year growth adds another 15-30 cm. Under favourable conditions, seedlings may reach a total height of 1.2 m after three seasons of growth. Aspen seedlings may compete favourably with other tree seedlings but not with aspen suckers, sprouts of various shrubs, or tall herbs (Heeney *et al.* 1980). This is particularly important in much of northeastern British Columbia, where *Calamagrostis canadensis* and *Epilobium angustifolium* are abundant.

The literature review did not reveal any data on changes in stem density during the first few years of seedling-origin aspen stands, although research recently initiated by the Alberta Forest Service may soon provide some information for such stands (J. Fochler, pers. comm., Alta. For. Serv., Spruce Grove, Alta., 1988). The several Michigan aspen stands reported by Graham *et al.* (1963) to be of seedling origin have not been described in the literature in terms of mortality and natural thinning during early stand development. Zackrisson (1985) estimated seedling mortality for *Populus tremula* in southern Sweden, where a recently burned 1000-ha area was estimated to have 9 million aspen seedlings per hectare 1 year after the fire, out of which an estimated 90 trees per hectare were expected to remain by the time they were of seed-bearing age.

If it were assumed that all clones on an area were initially established at about the same time, then the number of clones per unit area would be an indicator of the number of seedlings that survived to serve as the original stem of each clone in that area. In a Manitoba study by Steneker (1973), the largest clone mapped was 1.54 ha, but clone sizes averaged 0.08 ha in a 40-year aspen stand in Riding Mountain National Park and 0.006 ha in a 25- to 50-year stand in Agassiz Forest

Reserve. The maximum number of clones recorded in a 0.04-ha plot was 40. This translates into 1000 clones per hectare which, if the clones were all established at about the same time, would have required 1000 surviving seedlings per hectare. At least one investigator (Bertenshaw 1965) did conclude that clone size is influenced by the pattern of initial seedling establishment more than it is by site. However, if new seedlings are periodically introduced into clone-covered areas, then present clone size may be a poor index of the number of seedling-origin stems that originally occurred on any given hectare of land now dominated by distinctly recognizable clones.

12.2.2 Early growth of sucker-origin aspen

Aspen suckers have a much more rapid growth rate than seedlings in the early years, a difference that can last up to 30 years before trees of seedling origin reach their period of most rapid height growth. Suckers typically grow 1-2 m in the 1st year, but have been recorded as high as 2.7 m after one growing season; in the 2nd and subsequent years, growth of dominant suckers is commonly 0.5-1.0 m/yr (Horton and Maini 1964). In young aspen stands in Alberta and Saskatchewan, heights of dominant suckers averaged 1.7 m at the end of the second growing season, 2.4 m at the end of the third, 3.0 m at the end of the fourth, and 3.5 m at the end of the fifth (Bella and DeFranceschi 1980). The rapid growth of aspen suckers is accompanied by rapid development of their reproductive mechanisms: aspen suckers of fire origin have been reported to produce flowers at 6 years of age (Barnes 1966), and the newly developed roots of suckers are known to produce new suckers within 3 years (DeByle and Winokur 1985). In vegetative propagation experiments, Farmer (1962) noted that even a 1-year-old sucker was able to develop new suckers prolifically within 2 weeks of being severed from an actively growing stem.

Aspen may also reproduce vegetatively from stump sprouts and collar sprouts. Horton and Maini (1964) indicated that the three forms of vegetative reproduction did not differ appreciably in height growth during the first few years. These researchers believed that rotting of the parent stump is likely to influence the growth of stump sprouts negatively because root suckers and collar sprouts rapidly develop their own root system. In an Ontario study area where 1-year-old aspen regeneration was made up of about 76% root suckers and 24% collar sprouts, Horton (1984) recorded an average height of 0.72 m for dominant suckers and 0.80 for dominant root collar sprouts at the end of the first growing season.

12.2.3 Density changes in sucker-origin stands

The naturally decreasing sucker density that occurs in the first few years of stand development is supported by abundant published data (Steneker 1967; Pollard 1971; Bella and DeFranceschi 1980; Perala 1984; Bella 1986). Age density relationships from these and other references are summarized in Table 6. In general, the sucker density rapidly declines when suckers are extremely numerous after clearcutting. The least vigorous suckers die during the first 1 or 2 years, leaving one or two dominant suckers in each clump. Pollard (1971) documented the distribution of biomass by diameter classes as a young aspen stand at Petawawa, Ontario, progressed through natural thinning from age 4 to age 7. In each of these 4 years, most of the biomass occurred in the upper and middle dbh classes. Biomass in the form of small shoots (low dbh classes) decreased with each successive year. Pollard (1971) concluded that the increase in biomass of the stand as a whole depended entirely on the development of the upper dbh classes. Annual reductions in stand density were largely a result of the mortality of stems under 1 cm dbh. The significance of this observation is that, in short rotation management, the proportion of very small stems (which could downgrade the quality of a final product) rapidly diminishes each year. For example, Pollard's data revealed that at 4 years, 16% of the biomass occurred in shoots under 2 cm dbh; at 7 years, these shoots formed only 4% of the biomass.

What are the maximum stem densities that might be encountered in young aspen stands? From sampling sites in Alberta and Saskatchewan--which are ecologically similar to sites in the Dawson Creek and Fort St. John TSA's--the highest density class recorded by Bella and DeFranceschi (1980)

showed the following progression of density with age: 280 000 stems per hectare at age 2; 190 000 at age 3; 125 000 at age 4; and 80 000 at age 5. In approximately the same sampling region, within the Mixedwood and Lower Foothills sections of the Boreal Forest Region from the Manitoba-Saskatchewan boundary to the Alberta-British Columbia boundary, Peterson *et al.* (1982) recorded aspen stands with sucker densities as high as 433 000 stems per hectare at age 2, and 201 000 stems per hectare at age 3 (Table 10). However, these latter examples are from a study that deliberately searched for upper limits of standing crop and stand density in young stands.

TABLE 10. Height of tallest stem, stand density, foliage/wood ratio, above-ground standing crop, and foliage dry weight for Alberta and Saskatchewan aspen stands, listed by increasing stand age (Source: Peterson *et al.* 1982)

Plot no.	Age	Ht. of dominant stem cm	Stems per ha '000	% foliage[a]	% wood[a]	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Foliage dry wt t/ha
330	2	167	432.9	32.5	67.5	1.73	0.70	2.27
317	3	258	95.5	23.0	77.0	1.73	0.76	1.75
327	3	293	108.3	17.0	83.0	3.41	1.49	2.53
363	3	283	201.4	20.1	79.9	2.36	1.13	2.27
1	4	462	44.6	25.0	75.0	3.03	1.25	3.12
97	5	412	101.1	14.3	85.7	6.40	2.96	4.23
308	11	735	69.2	11.0	89.0	7.96	3.72	4.09
311	11	527	95.5	11.7	88.3	5.17	2.31	2.70
27	12	643	38.2	10.0	90.0	6.86	2.84	2.84
30	12	621	67.6	8.5	91.5	11.86	5.83	4.95
31	12	701	52.5	12.5	87.5	12.07	6.02	7.52
32	12	541	66.8	9.2	90.8	9.71	4.87	4.48
53	12	410	75.6	10.8	89.2	4.96	2.27	2.45
54	12	551	36.6	7.9	92.1	6.54	3.28	2.59
300	12	464	67.7	18.4	81.6	4.68	2.05	3.77
2	13	670	38.2	19.4	80.6	7.95	3.26	6.32
7	13	695	39.0	10.6	89.4	6.53	3.08	3.26
90	13	628	100.3	10.4	89.6	8.75	4.28	4.45
10	13	761	70.8	8.0	92.0	13.63	6.63	5.30
57	13	530	152.8	9.1	90.9	8.78	4.21	3.83
91	14	748	79.6	10.5	89.5	15.57	7.33	7.69
359	14	610	105.9	11.9	88.1	10.59	5.20	6.19
20	18	968	25.5	9.7	90.3	15.02	7.04	6.80
36	29	628	21.5	14.5	85.5	14.74	6.40	9.28

[a] Percentages based on fresh weight.

Although information presented by Bonnor (1985) indicates there are higher standing crops of hardwoods in northeastern British Columbia than in the area sampled by Peterson *et al.* (1982), the "upper limits" by the latter authors are a guide to what might be expected in some of the most productive aspen stands of similar age in the Dawson Creek and Fort St. John TSA's.

12.2.4 High foliage standing crop in young stands

A notable feature of the data reproduced in Table 10 is the rapid development of a foliage standing crop comparable to that in older stands. For example, the foliage standing crop in excess of 7.5 t/ha at ages 12 and 14 is greater than in some stands several years older, and is not much less than the foliage dry weight of 9.3 t/ha in a 29-year-old stand. There is other evidence from the literature that canopy closure and development of foliage standing crop comparable to that in mature stands can occur relatively early in aspen. For example, Perala (1984) followed the first 7 years of the development of aspen sucker stands on a good and an excellent site in Minnesota. He noted that, according to the 3/2 power law of self-thinning (Drew and Flewelling 1977), the good site was fully occupied at age 2 and the excellent site by age 3. Similarly, Pollard (1970, 1971) noted an aspen stand at Petawawa, Ontario, in which the canopy had apparently closed and was rapidly approaching maximum development at age 4. The sampled stand had a leaf area index of 2.4 in the 5th year, almost as much foliage per unit area of soil surface as in a 15-year-old stand where leaf area index was 2.9. In fact, a mature 52-year-old stand at the Petawawa study site, with a leaf area index of only 1.6, supported less foliage per unit area than did the 5-year-old stand. The rapid development of the "photosynthetic factory" in young sucker stands is of major importance to aspen silviculturists.

12.2.5 Diseases in young aspen stands

There is abundant literature on the pathology of mature aspen stands. For example, recent reviews by Hiratsuka and Loman (1984) and Navratil (1987) provide guidance on decay management for established stands. With regard to young aspen stands, Zalasky (1970) believed that problems initiated by pathogenic organisms are relatively rare in aspen and poplar regeneration, with most injuries resulting from non-biological causes such as frost, mechanical injury, or fire. However, other investigators have stressed that young aspen stands do host a number of endemic insects and pathogens that cause injury (Perala 1984). Some researchers contend that young suckers without at least one injury per stem are rare (Millers 1972).

The pathological quality of aspen suckers has been investigated in detail in northern Ontario by Basham and Navratil (1975); Kemperman *et al.* (1976); Gross and Basham (1981); and Basham (1982a,1982b). Of the cankers, *Cytospora chrysosperma* was present in most stands sampled, but in no instance was it a cause of death. *Hypoxylon* canker was found by these authors to be relatively unimportant in aspen suckers or in young stands, in contrast to its severity in older stands. Of the foliar diseases, aspen shoot blight (*Venturia macularis*) is considered to be one of the most important diseases affecting sucker regeneration. In years of severe blight, sucker stands with 100% terminal infection are common, and such stands tend to stagnate. The stubs of the terminals that remain following shoot blight infection become new infection sites for other canker and rot-causing agents (Gross and Basham 1981). Root rot and stain defect were also present in a large percentage of aspen suckers, a condition that appears to be fairly constant across northern Ontario, especially for *Armillaria mellea*.

Incidence of infection from *Hypoxylon* canker in Lake States aspen is lowest in pure aspen stands and increases as the proportion of other species in the stand increases, especially when there is an understorey of hardwoods (Anderson 1953). Damage from *Hypoxylon* canker is more evident on poor sites than on better sites. Slower growing trees on poor sites are exposed to infection longer before reaching merchantable size and, at any given age, full stocking on poor sites requires more trees per acre (Anderson 1953).

On a Wisconsin site that was considered favourable for aspen, root systems associated with healthy-appearing dominant or co-dominant aspen were found to have *Armillaria* root rot at ages 3, 9, and 15 years after clearcutting (Stanosz and Patton 1987b). Infection occurred by rhizomorph penetration, mycelial growth through the roots of the parent stumps, and by contact with colonized roots. Both the number of infected trees and the number of lesions per infected tree were greater as

the time interval after cutting increased: 72% of the 15-year-old stands were infected compared to 44% in 9-year-old stands and 24% in 3-year-old stands.

In a separate article, Stanosz and Patton (1987a) reported *Armillaria* root rot in aspen suckers and root collar sprouts from short-rotation plots on highly productive sites in Minnesota and Ontario.The consistently higher root rot incidence in root collar sprouts than in suckers was considered to be evidence of the ability of *Armillaria mellea* to spread through the slowly dying but interconnected root systems of the original parent clone. The Minnesota plots, in particular, showed the effects of cumulative infection and mycelial spread that may have begun before the initial harvest and continued during successive short rotations. Sprouting was severely reduced at both the Minnesota and Ontario locations after three or more rotations of 4 or 5 years duration. This suggests that *Armillaria* root rot may limit rotation length and the number of times that aspen stands can successfully regenerate vegetatively (Stanosz and Patton 1987a).

During the first 7 years of aspen stand development on a good and an excellent site in Minnesota, Perala (1984) monitored three endemic injuries that are brought on by disease or insects: shoot dieback, galls, and lesions. The frequency of these three types of injuries were significantly higher on the good site than on the excellent site. Shoot dieback was particularly devastating to the growth of suckers on the good site, where 59% of the stems suffered in at least 3 of the 5 years observed. On the excellent site, 69% of the suckers experienced only 1 year of dieback damage.

Several other pathogens have been noted in young aspen stands. For example, in a study of mortality during the first 7 years of aspen stems at Petawawa, Ontario, Pollard (1971) noted that all of the large dead stems were infected with *Diplodia tumefaciens*. Also in Ontario, a canker caused by *Neofabraea populi* was noted on aspen 3-6 years of age, but not many of the infected stems were killed (Thompson 1939).

12.2.6 Insect influences in young aspen stands

Remarkably little literature exists on the influences of insects on young aspen stands. Webb (1967) indicated that in heavily stocked aspen stands the death of a number of the trees, particularly the suppressed and intermediate individuals most vulnerable to borer and fungi attack, will improve the health of residual trees. He suggested that the gradual removal of these aspen stems through such natural agents may result in less disturbance, and may be less costly than silvicultural thinnings.

Some forest entomologists have hypothesized that dense aspen sucker stands can withstand the effects of insects simply because the stands are so dense and have few openings and edges. This raises the question of whether insect influences will be more prevalent if future managed stands have lower sucker densities than fire-origin stands (W. Ives, pers. comm., Canadian Forestry Service, Edmonton, Alta., 1988). In Ontario, there has been some concern that post-harvest sucker stands may not be as uniformly dense as sucker stands of fire origin (Basham 1981). Because the entomology of the young stages of today's predominantly fire-origin sucker stands is generally unresearched, it is not possible to predict what the insect influences might be if future forest managers are dealing with stands of lower sucker density or with many discontinuities.

12.2.7 Fire relationships in young aspen stands

Existing information on aspen-fire relationships does not provide much detail on the responses of young sucker stands to fire. Although fuel is often not very abundant in young aspen stands (Brown and Simmerman 1986), it is known from prescribed burn experiments described by Kiil (1970) that fire can kill aspen saplings. Zalasky (1970) also discussed fire damage to "juvenile" aspen, without specifying the age of stems involved. If there is sufficient fuel for a fire to pass through a young sucker stand, fire intensity will be great enough for the thin and succulent bark of aspen to be injured. Zalasky (1970) noted droplets of gum oozing from injured aspen bark several days after a fire. These pinhead openings can develop into sites of bark collapse, and eventually serve as entry points for canker-causing fungi.

12.2.8 Other Influences in mature aspen stands

The existing literature defines many other factors that influence established or mature aspen stands, such as forest tent caterpillar (Hildahl and Campbell 1975; Ives 1984); and physical factors such as snow loading (Gill 1974) or frost (Strain 1966; Zalasky *et al.* 1968) and fire (Lutz 1956, 1960; Horton and Hopkins 1965; Kayll 1968; Rowe and Scotter 1973; Perala 1974; Kelsall *et al.* 1977; Viereck and Schandelmeier 1980; Alexander and Euler 1981; Brown and DeByle 1987). More specifically focussed on northeastern British Columbia, Parminter (1983a,1983b) carried out a detailed study of fire-ecological relationships in the Fort Nelson TSA. These cited references all deal primarily with mature stands and for this reason are not summarized here.

12.2.9 Autecology of species in aspen ecosystems

Considerable information exists on the autecology of individual plant species that may be associated with boreal hardwoods (Krajina *et al.* 1982; Haeussler and Coates 1986), but little is available on interspecific relationships between species that co-exist in boreal hardwood ecosystems. For example, few data exist on the possible differences in growth rates of boreal hardwood species when they occur in single-species stands, with other species of boreal hardwoods, with conifers, or in different kinds of understorey and shrub communities. Studies such as those by Smith (1981), who documented relationships between black cottonwood and red alder, or Berry (1982), who did similar work with aspen, pine and spruce, are required for several kinds of mixed stands involving boreal hardwoods. The recent study by Hamilton and Yearsley (1988), describing vegetation development after clearcutting and site preparation in the Sub-Boreal Spruce Zone, shows this knowledge gap is now recognized as a silviculturally important subject.

12.2.10 Wildlife relationships

Loss of aspen regeneration to browsing animals was not singled out as a forestry concern by the working group. The literature suggests that in some regions, such as the Rocky Mountain Region described by Schier *et al.* (1985), browsing and trampling by wildlife and livestock can seriously reduce aspen regeneration. Where this is a threat, scattered slash from aspen logging can provide young sucker stands with some protection from browsing animals. Light browsing by animals has little effect on the eventual stem form or height growth of aspen because a single dominant shoot develops from the uppermost lateral bud after the terminal is browsed (Graham *et al.* 1963; Maini 1966; Schier *et al.* 1985).

Habitat studies and carrying capacity studies by researchers specializing in wildlife or livestock have generated considerable information on the ecology of the species being browsed or grazed. Forest managers often overlook this source of information, much of which is directly relevant in cases where choices must be made between forestry, wildlife, or agricultural uses of land.

12.3 Interim Solutions Based on Available Information

As with stand tending (Section 8.3), a practical interim measure for the silviculture of young aspen stands is to follow the advice of Perala (1972):

> Little care is needed once a fully stocked, rapidly growing, even-aged aspen stand has been established. If too dense, the stand will thin itself with little loss in growth due to competition.

The available literature, especially the work of Basham and co-workers in Ontario, focusses on the pathological quality of suckers more than on any of the other biological or physical factors that can influence aspen regeneration. Although the literature suggests that managers of young aspen stands should be on the lookout more for pathological problems than for entomological ones, this may simply reflect the relative lack of information on insect influences in these young stands.

12.4 Suggested Follow-up

The response of boreal hardwood regeneration to the many biological and physical factors that could be influential is a vast subject deserving more analyses and research. However, any additional review of available information should not be initiated until specific problems or hypotheses are defined. In the meantime, research personnel, as well as Regional and District forest managers, should continue to record the circumstances associated with any unusual mortality, poor growth, or other abnormalities in young established stands of boreal hardwoods. Such observations and records could then be used to develop hypotheses for further literature review, data collection, or field experimentation.

Although there is little in the literature to verify the assumption, interspecific competition between boreal hardwood regeneration and its associated tree, shrub, herb, and grass species, may be as important a question to pursue as is pest management of young stands. Ministry of Forests personnel already have strong interests in further elaborating ecological relationships in hardwood-dominated ecosystems. These ecological studies, with particular emphasis on interspecific relationships in young stands, should be continued. Work of this kind should build upon the review prepared by Coates and Haeussler (1986) and the work of Hamilton and Yearsley (1988).

13 COMPACTION OF SOILS

13.1 The Problem

The working group was concerned that soil compaction as a result of silvicultural and harvesting operations could significantly reduce aspen suckering. This is a reasonable concern, because compaction is greatest near the surface, where most of aspen's sucker-producing root buds are located. The potential for compaction is known to be higher with summer logging than it is with winter logging (when the ground is frozen), but how evident these seasonal differences are and how much site influences them are not well known.

13.2 Information from the Literature

This review did not identify any literature that focussed on the overall effects of compaction from harvesting operations in northeastern British Columbia. The most closely related work is by Corns (1988), who described compaction studies in the Alberta foothills. Recently completed reports, which were not available before completion of this review, deal with: soil degradation as a factor affecting forest productivity in British Columbia (Utzig and Walmsley 1988); guidelines for timber harvesting on interior British Columbia sites of various degradation sensitivities[5]; and impacts of forest harvesting and renewal on soil properties and site productivity[6].

A review by Carr (1987), based on a case study near Fort St. James, focussed on landings rather than the overall compaction effects of forestry operations. Landings occupied an average of 5% of cutover land, and skid roads occupied an average of 16% in the Fort St. James study area – an estimate that is assumed to be applicable to harvesting operations in northeastern British Columbia. On steeper terrain, the overall area of landings is reduced, but the area occupied by skid roads can increase from 16% to at least 30%[7]. Although Carr's study concentrated on landings –the characteristics of which cannot be extrapolated to the entire harvested area – some of the recorded phenomena are generally applicable. For example, summer landings have bulk densities greater than winter landings, with the result that 6 years after logging tree growth loss was 45% on summer landings in contrast to 30% on winter landings.

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5 Lewis, 1988.
6 Lousier, 1988.
7 A. McLeod and E. Hoffman. 1984. A pilot study of soil disturbance on selected cutovers in the Prince George Forest Region. B.C. Min. For., Prince George, B.C. Unpubl. report.

All of the interior forest regions now have rehabilitation guidelines for landings and main skid roads. These guidelines, although recommending soil decompaction to a depth of 30 cm, do not say what decompaction measures are needed for cutover lands beyond the landing areas and skid roads. As well, the emphasis to date has been restricted to coniferous regeneration responses to compaction. Consequently, published information is scarce about the influences of soil compaction on regeneration of boreal hardwood species in cutblock areas away from the landings and skid roads.

13.2.1 Influence of skidding on aspen regeneration

In Arizona, Schier *et al.* (1985) reported aspen regeneration failure where heavy skidding traffic had occurred. Areas with failed regeneration remained treeless for 5-10 years, and up to 23 years in one case. Similar failures to regenerate aspen following logging activities were reported from Minnesota by Zasada and Tappeiner (1969). Jones and Shepperd (1985) also cautioned that care must be taken to avoid skidding damage to clonal root systems. Darroch[8] concluded that aspen are sensitive to soil compaction from heavy equipment, based on the statement by Perala (1977) that for best aspen sucker regeneration the soil must be well drained and well aerated.

13.2.2 Compaction studies outside of the boreal mixedwood region

Most of the available information comes from compaction studies done in forest ecosystems of the western United States, and from a number of soil studies in heavily used recreation areas. In the latter case, several kinds of disturbances may be involved simultaneously, including soil compaction, surface erosion, and tree root exposure. Soil compaction is included in the management interpretations developed by Corns and Annas (1986) for ecosystem associations in west-central Alberta, but their soil compaction hazard rating was also based on studies from the Pacific Northwest region (Boyer 1979) rather than from specific studies in boreal ecosystems.

The soil compaction hazard rating described by Corns and Annas (1986) for western Alberta (Table 11) is of possible use in northeastern British Columbia. The degree of soil compaction is influenced by several soil physical properties, including texture, structure, percentage and type of coarse fragments, percentage organic matter, and organic layer thickness (Boyer 1979; Corns and Annas 1986). In Alberta, soils of the Lower Boreal Cordilleran and Boreal Mixedwood ecoregions are considered to be more susceptible to compaction than those in the foothills within the Upper Boreal Cordilleran Ecoregion. The main reason for this distinction is an increasing predominance of fine-textured tills of continental ice-sheet origin as one progresses northeastward from the upper foothills.

13.2.3 The key influences of compaction

From recent research that examined compaction by forestry equipment and its effects on coniferous seedling growth in the Lower and Upper Foothills Sections of west-central Alberta (Corns 1988), two observations are relevant for the present review. In four soils tested, compaction resulted in significant reductions in nine expressions of coniferous seedling growth (maximum root depth, maximum root depth in soil core, total weight, shoot weight, root weight, stem diameter, shoot height, seedling survival, and shoot weight:root weight ratio). The compaction effects on tree growth, based on the coniferous species used in testing, may not become evident until the roots exploit soil at depths of 20-30 cm, possibly in 10-20 years depending on the intensity of traffic. The second important point is that soil compaction in Alberta boreal ecosystems appears to persist for several decades, despite annual freeze-thaw cycles in the soils. This is considered to be a result of hydrous mica clays, which are characterized by a non-expanding lattice structure that would be affected little by wetting-drying cycles. Frequent low soil moisture levels in late fall and winter in the study area also reduce the effectiveness of freeze-thaw cycles as a natural decompaction process (Corns 1988).

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8 B.E.Darroch. 1986. Silviculture treatments to improve the growth of trembling aspen in British Columbia. Univ. B.C., Faculty of For., Vancouver, B.C. Unpubl. grad. essay. 26p.

Table 11. Soil compaction hazard for forest ecosystems of west-central Alberta. (Source: Corns and Annas 1986, based on adaptation from Boyer 1979)

Texture[a]	Coarse fragments	L & F (humus) thickness	Structure	Character of coarse fragments	Soil compaction hazard rating[b]
	<35%	<5 cm	Strong	All	M
			Mod. & weak	All	H
		>5 cm	Mod. & weak	All	H
			Strong	All	M
L, SiL, SiCL, CL, Si, HSL vfSL	35-60%	<5 cm	Mod. & weak	Rounded	M
				Angular	M
			Strong	All	L
		>5 cm	Mod. & weak	Angular	L
				Rounded	M
			Strong	All	L
	>60%	Any	All	All	L
LS, S	Any	Any	All	All	L
	>35%	Any	All	All	L
SiC, C SC, SCL	<35%	<5 cm	Strong	All	L
			Mod. & weak	All	M
		>5 cm	Mod. & weak	All	M
			Strong	All	L

[a] Texture symbols are as follows: L = loam(y); Si = silt(y); C = clay; S = sand(y); H = heavy; and vf = very fine.
[b] L = low; M = moderate; and H = high. In making a rating, consider the characteristics of the litter and upper 30 cm of mineral horizon(s). A wet or moist condition is assumed. The horizon that gives the poorest rating is used.

In undisturbed soils typically found in forested areas, bulk densities are lower at the surface and increase with depth. Therefore, it is not surprising that test results by Froehlich *et al.* (1980) confirmed that repeated passes with loaded logging vehicles caused the greatest increases in soil density near the surface. In these tests, carried out in the Tahoe National Forest, bulk density increases at a 15 cm depth averaged about 50% of the bulk density increases at 5 cm after 20 trips.

Wingate-Hill and Jacobsen (1982) reviewed the evidence that soil disturbance and compaction can adversely affect tree growth and long-term productivity of a site, but found that the effects are variable and not well quantified. The 30-cm top soil profile, where compaction is greatest, is also the zone of greatest root mass and nutrient supply to trees, in addition to being important for infiltration of water during short-duration, high intensity rainstorms. In its natural state, the upper 30 cm of soil normally has a high hydraulic conductivity and high water storage capacity (Wingate-Hill and Jacobsen 1982).

From several studies in the Pacific Northwest, Froehlich and co-workers (Froehlich 1973, 1978, 1979; Froehlich *et al.* 1980, 1981; Adams and Froehlich 1981; Andrus and Froehlich 1983; Froehlich and McNabb 1984) documented the key effects of soil compaction from logging equipment, especially high-speed skidder vehicles. Several key effects were noted : soil density increased primarily between depths of 5 and 10 cm; soil density increased most during the first few trips; density

continued to increase slowly in amount and depth with the number of trips, especially as the litter layer was removed; and litter and slash layers tended to remain in place for the first 20 passes. On sloping areas, fewer passes were needed to disturb surface soil. It was also observed in studies of Oregon clay loam forest soils that the surface 15 cm of soil was compacted more by uphill than by downhill yarding (Sidle and Drlica 1981).

13.2.4 The importance of compaction for near-surface conditions

The fact that ground skidding causes the greatest increase in soil density near the surface, but is negligible below 30 cm, may be particularly important for aspen which is known to have most of its sucker-producing roots within 5 cm of the soil surface (Horton and Maini 1964; Jarvis 1967). Rooting depths examined in boreal forest communities near Slave Lake, Alberta (Strong and LaRoi 1983, 1985), determined that the upper 25 cm of the soil profile is the zone of primary importance for roots of upland boreal forest species; over 90% of all the root biomass sampled by these researchers was located between 5 and 20 cm below the forest floor.

In the Slave Lake area, aspen stands on sandy soil had the highest overall root densities of all communities sampled on mineral soil. The maximum root density recorded in an aspen stand on sandy soil occurred at the mineral-organic interface, where there were 20 921 roots counted in a soil volume of 0.10 m^3 (upper 10 cm of soil on a 1-m^2 area). Young stands had higher root densities near the surface than did older stands on the same soils. Maximum rooting depth for aspen on a sandy soil was 130 cm. Aspen stands on clay loam reached their maximum rooting depth in less than 20 years (Strong and LaRoi 1983). These site differences in rooting habit suggest there may be important site influences on the responses of aspen root systems to compaction.

13.2.5 Natural recovery from soil compaction

Recovery time from soil compaction varies according to site conditions. In the Pacific Northwest, Froehlich (1973, 1982) documented circumstances in which compaction effects are long-lasting. However, soils with very active plant roots and active soil organisms, or regular freeze-thaw and wet-dry cycles, are most likely to recover quickly from compaction (Adams and Froehlich 1981; Froehlich and McNabb 1984). Froehlich and McNabb (1984) indicated that for these processes to be effective, several criteria must be met: the soil must be sensitive to the process; the climate must produce the necessary temperature and moisture regimes; and the cycles must occur frequently. Also, coarse-textured soils with relatively weak soil structure recover more readily than fine-textured soils.

13.2.6 Avoiding or correcting the effects of compaction

In North America, the problem of compaction has been avoided or lessened by: use of skyline or helicopter logging systems; selection of appropriate machinery in relation to soil type and moisture regime; or improved methods of skidding, including designated skid trail systems. Adams and Froehlich (1981) and Froehlich and McNabb (1984) urged the use of designated skid trails during both thinning and harvesting. They also recommended the use of specialized tilling in compacted areas to reduce compaction and enhance productivity. The use of designated skid trails, log winching, and specifications to limit the total area covered by trails are practices that have been shown to reduce soil compaction (Adams and Froehlich 1981; Froehlich *et al.* 1981).

Corrective measures for compacted soils have included tillage of vehicle trails by a selection of different implements (Andrus and Froehlich 1983), such as brush blades, rock ripper tines, disc harrows, and winged subsoilers. However, no single implement exists that is best for all circumstances. Clay soils in Oregon, which often remain moist year-round, respond best to disc harrows because of the tendency of clay soils to develop persistent clods when other tillage systems

are used (Andrus and Froehlich 1983). Application of bark mulch before compaction tended to reduce compaction effects in trials conducted in northwestern Vermont (Donnelly and Shane 1986). However, additions of mulch following compaction did little to ameliorate compaction-induced changes.

13.2.7 Compaction experience in recreational sites

For forested ecosystems in which aspen was a component, some additional literature is available pertaining to compaction following lengthy recreational use (Brinkman and Roe 1975; James *et al.* 1979; Mackintosh 1979; Monti and Mackintosh 1979). Intense use resulted in loss of surface organic horizons, soil compaction, and reduced infiltration rates. Following the initial changes of soil compression and loss of surface litter, a thin, compacted mineral layer, or crust, forms at the soil surface. Legg and Schneider (1977), studying a hardwood stand that did not contain aspen, reported a 1-2 cm thick crust that formed on all heavily used campsites where litter was absent. Such crusts are sufficiently impermeable to severely limit movement of water to lower soil levels. With reduced infiltration, there can be increased surface movement of water and severe erosion from channelled water.

13.2.8 Compaction in agricultural soils

In reference to agricultural soils in the Peace River region of British Columbia, de Vries (1983) identified three effects of soil compaction. Compaction influences how rainfall is partitioned between infiltration and overland flow at the soil surface. Second, compaction affects plant growth by making water and nutrient use less efficient, mainly because the compacted layer interferes with seedling emergence and root penetration. Third, compaction causes an increase in clods in the cultivated portion of the upper mineral horizon. DeVries (1983) also noted that, in the Peace River region, climate is probably the most important cause of soil compaction, as a result of high intensity spring and summer rains and heavy snowpack in winter.

13.3 Interim Solutions Based on Available Information

This review did not identify any soil compaction data specific to sites dominated by boreal hardwoods. Studies are needed to document whether there are specific forest ecosystems in northeastern British Columbia and specific circumstances under which soil compaction can be a deterrent to aspen sucker development. Until that information is available, the most prudent course is to follow the suggestion by Revel *et al.* (1986) that, because aspen generally occurs on heavy textured soils that compact easily when wet, harvesting operations should cease during spring break-up and during periods of very wet weather. Although their study near Hudson Bay, Saskatchewan, did not measure soil compaction, Bella and DeFranceschi (1972) believed that winter logging might be more desirable both from silvicultural and operational points of view, as it would prevent excessive compaction and disturbance of soil on logging trails.

The literature summarized by Corns and Annas (1986) for their study area in west-central Alberta suggests that soil compaction can be minimized by keeping heavy machinery off the more susceptible soils when they are wet, by minimizing the area of logging roads on clearcuts, and by minimizing the number of passes over an area. On susceptible soils, most compaction occurs during the first pass over the area by heavy equipment (Rothwell 1978).

13.4 Suggested Follow-up

Compaction as a result of forestry operations needs to be documented specifically for the site, soil, and climatic characteristics of hardwood and mixedwood ecosystems in the Boreal White and Black Spruce Biogeoclimatic Zone. To locate compaction study areas, highest priority should be given to the

most productive alluvial hardwood sites and the most productive upland hardwood sites, because losses in productivity as a result of compaction would be most serious on such sites. The key objective in such study areas should be to document the circumstances, if any, where compaction from forestry operations is a deterrent to regeneration of boreal hardwood species.

14 EROSION

14.1 The Problem

Whether harvesting involves boreal hardwoods or softwoods, certain types of soils are expected to be susceptible to surface erosion. In northeastern British Columbia, surface erosion or rill-gully erosion is a concern on slopes after intense summer rain or during spring runoff, particularly on sites characterized by silty loams or fine sandy loams. However, these potential hazards are not unique to hardwood-dominated stands.

14.2 Information from the Literature

Soil degradation in the forest regions of British Columbia has been the subject of inquiry by several researchers, amongst them Smith and Wass (1976, 1979, 1980 and 1985), Ballard (1983), Krag *et al.* (1986), Lewis (1988)[9], Lousier (1988)[10], and Utzig and Walmsley (1988). Krag *et al.* (1986) believed that to explain soil disturbance fully, operational factors such as layout of logging need to be considered along with environmental influences. In southeast British Columbia, Krag *et al.* (1986) found that soil disturbance from logging was significantly greater on ground-skidded than on cable-yarded cutovers, averaging 40-50% and 22-30%, respectively regardless of season.

14.2.1 Existing erosion control guidelines

There are a relatively large number of published manuals and guidelines on methods to reduce erosion during road-building and forest harvesting operations (Geale 1966; Rutter 1968; C.D. Schultz & Co. Ltd. 1973; De Pape *et al.* 1975; Johnson and Wellburn 1976; Lengelle 1976; Hedin 1978; Rothwell 1978; Alberta Forest Service 1979; Carr 1980; Schiechtl 1980; Toews and Brownlee 1981; Singh 1983; Still and Thompson 1983). These manuals confirm that soil erosion following road-building, forest harvesting, and other surface disturbances is influenced predominantly by geomorphic, edaphic, and meteorological variables, rather than by the type of forest that is harvested. There is no evidence from the literature that distinctive erosion problems would exist in northeastern British Columbia because a site is dominated by hardwoods or because the harvesting operation specifically involves hardwoods.

Erosion potential is influenced by compaction (Section 13). Reduced infiltration as a result of compaction can lead to surface runoff from rainfall intensities that exceed the soil's infiltration capacity. Such runoff can concentrate on or near existing roads, adding to the stress already present on drainage systems. If the compacted area is widespread, surface runoff can significantly increase storm flow in streams. This can lead to bed scour of streams, altered water quality, sediment loading, and damage to fish habitat – quite apart from the reduction of terrestrial productivity as a result of surface soil loss (Adams and Froehlich 1981).

A soil water erosion hazard rating system, similar to the soil compaction hazard rating system (Table 11), was prepared by Corns and Annas (1986) for west-central Alberta. This rating system is considered to be applicable to northeastern British Columbia and is reproduced in Table 12.

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9 Lewis, 1988.
10 Lousier, 1988.

14.3 Interim Solutions Based on Available Information

Steps to eliminate or reduce soil erosion should be no different in hardwood-dominated stands than in mixedwood or coniferous stands. Guidelines contained in the handbooks and manuals identified in Section 14.2 should be followed in any forestry operations involving hardwood use. The overall goal should be to avoid loss of surface soil as a result of erosion, because such a high portion of the site nutrient pool occurs in the litter layer and upper few centimetres of mineral soil. When this surface material is removed, as often happens at forest landings, the residual soil is of relatively poor quality especially in nitrogen and phosphorus content. The excellent text by Schiechtl (1980) suggests practical methods for use of vegetation to stabilize slopes and reduce erosion.

TABLE 12. Soil water erosion hazard (Source: Corns and Annas 1986)

Parent material	Texture B horizon[a]	Slope (%)	Hazard[b]
Till	Medium to coarse	<10	L
Colluvium, glaciofluvial gravels, unconsolidated bedrock (sandstone, shale), organic	Variable	<5	L
Till	Fine to moderately fine	< 10	M
Till	Medium to coarse	10-15	M
Till	Very stony variable texture	16-60	M
Colluvium	Variable	5-30	M
Eolian	Coarse	0+	M
Unconsolidated bedrock	Variable	5-9	M
Glaciolacustrine	Fine	0+	H
Glaciofluvial, fluvial	Medium to coarse	0+ (especially Gleysols)	H
Till	Fine to moderately fine	> 10	H
Till	Medium to coarse	> 15	H
Colluvium	Variable	> 10	H

a Textural groups are as follows: **fine** - sandy clay, silty clay, heavy clay; **moderately fine** - clay loam, sandy clay loam, silty clay loam; **medium** - very fine sandy loam, loam, silty loam, silt; **moderately coarse** - sandy loams; **coarse** - sands, loamy sand.

b L = low, M = moderate, H = high. Ratings assume unvegetated surface. Dense vegetation cover will reduce hazard by at least one class.

If current erosion control practices are applied to any new hardwood harvesting operations, there may be no need to search for interim solutions. This does not rule out the refinement of erosion control practices in the future; the key point is that effective techniques are known already and the main challenge is to create an administrative and regulatory setting that ensures existing knowledge is applied. Revel *et al.* (1986) gave examples of practices that are already known to minimize erosion problems. These include: avoidance of aspen harvesting at times when the typically heavy-textured soils of good aspen sites are saturated; maintenance of unharvested forest strips about 25 m wide on both sides of creeks and drainage channels; and restriction of harvesting to the period of frozen ground if there are highly erodible soils or steep slopes over 30%. As in any post-harvest clean-up, treatment of hardwood harvest areas should include the seeding of legumes and grasses on landings and disused roads to reduce erosion.

14.4 Suggested Follow-up

No specific follow-up steps are recommended now, but regional and district personnel should document the circumstances associated with any specific erosion problems noted in areas where hardwood or mixedwood stands have been harvested.

15 GENE CONSERVATION

15.1 The Problem

The literature shows that certain aspen clones possess superior growth. The same is true for individual trees of black cottonwood and balsam poplar. The working group concern is that these superior genotypes could be lost unknowingly if they are not identified, mapped, and marked in the field. Standards are needed for selecting superior boreal hardwood trees and clones, combined with the maintenance of detailed records on locations and characteristics of genetically superior hardwoods.

15.2 Information from the Literature

15.2.1 Clone differentation

The ability to differentiate aspen clones is of practical importance because superior clones can be several times more productive than inferior ones. There are also marked clonal differences in suckering ability and disease resistance. Many authors have documented clone-to-clone variations in morphology, tree quality, and physiological responses (Garrett and Zahner 1964; Horton and Maini 1964; Barnes 1966, 1969, 1975; Steneker and Wall 1970; Schier 1973; Copony and Barnes 1974; Jones and Trujillo 1975; Kemperman 1977; Lehn 1979; Lehn and Higginbotham 1982; Heidt 1983). For the field forester, the morphological features most helpful for differentiating aspen clones have been defined by Barnes (1966), Steneker and Wall (1970), Kemperman (1977), and Horton (1984). Where clonal differences are expressed through differential growth rates, an experienced observer can recognize superior, average, and inferior clones. Genetic studies involving electrophoretic analysis of iso-enzymes offer the most precise techniques for clonal differentiation (Cheliak 1980; Cheliak and Dancik 1982; Cheliak and Pitel 1983).

15.2.2 Encouragement of favoured clones

Both Perala (1981) and Horton (1984) noted the potential for clonal expansion. For example, a clone 0.1 ha in size has been noted to expand in area by 200-300% at each rotation, and a large clone of 1 ha could increase by 50% during one rotation. Initial comments by Horton (1984) on the "root tree" method of regeneration of specific clones noted two practical issues: the danger of losing root trees to windfall, and the erratic distribution of superior clones. Heeney *et al.* (1980), citing a personal communication from Dr. J.S. Maini, described one possible method for promoting the best clones in a stand. Maini's suggestions are cited below:

> Before any logging takes place in the stand, identify and mark (blue paint) one or two stems as "root" trees in each good clone to keep at least some of the root system alive. Five to ten such trees per acre would be suitable. Log all the unmarked trees during mid-summer, leaving as much slash and debris on the site as possible to inhibit sucker formation and growth. Leave the site for two to three years to exhaust the carbohydrate reserves of the poor clones. Finally, harvest the marked trees and treat the site to remove slash, debris and any existing aspen suckers. Subsequent sucker regeneration in the stand will be largely from the best clones whose vigour has been preserved by the "root" tree. This is considered experimental at this time and requires further testing before it can be recommended as a management technique.

Zahner and Crawford (1963) and Lehn and Higginbotham (1982) are amongst those who advocate the importance of managing aspen on a clonal rather than a stand basis, as a way to promote superior clones. However, Navratil (1987) suggested that the concept of clone manipulation may have been oversold: first because clonal management in stands where clones are well separated is very unlikely; and second, yearly gains in expansion of promoted clones are too small to make the practice operationally worthwhile. Navratil (1987) predicted that it may take five or six rotations before significant distribution of superior clones can be achieved.

15.2.3 Clone selection to meet product standards

Distinct aspen clonal differences have been determined for both wood density and fibre length based on a study of clones from north-central Alberta (Yanchuk 1982, Yanchuk *et al.* 1983, 1984). The effect of clones accounted for 35% of the phenotypic variation of wood density and 43% of fibre length (van Buijtenen *et al.* 1959, Einspahr *et al.* 1963). An observation of practical importance is that 4-year-old suckers that exhibited long fibres also had long fibres at later ages, a characteristic that could aid early detection of preferred clones if fibre length were of interest to the user of the aspen resource. Kennedy(1968) suggested that the selection of clones possessing both fast growth and high wood density may be an important objective.

If black cottonwood is propagated at some time in the future for reforestation of certain sites in northeastern British Columbia, attention should be given to growth differences between different clones or individual trees. For example, Stine *et al.* (1981) examined black cottonwood provenances along a north-south gradient from Portland to Roseburg in the Willamette River valley of Oregon, and found that variation in stem production was greater within than among provenances. This suggests that, for black cottonwood, single-tree selection would be more profitable than provenance selection.

15.3 Interim Solutions Based on Available Information

The first opportunity to incorporate genetic considerations into boreal hardwood silviculture will likely arise in the context of encouraging clones that have been observed to possess superior growth rates or other desirable characteristics, and discouraging less desirable adjacent clones.

There has been ample documentation in the aspen literature that significant differences occur in growth rates from clone to clone. No reason exists to doubt that this pattern is found in boreal hardwood forests of northeastern British Columbia. If this assumption is correct, any inventory or ecological classification programs that involve the use of field crews should place high priority on instructing field personnel on methods to recognize, record, and map aspen clones that appear to possess above-average growth potential or other desirable characteristics. Studies elsewhere have confirmed that aspen clones that exhibit exceptionally large stems in relation to neighbouring clones on the same site commonly involve triploid genetic material. Triploid aspen has been of considerable interest to the pulp and paper industry in Europe and in the Lake States (van Buijtenen *et al.* 1958, Einspahr *et al.* 1963, Winton 1968). Aside from its desirable characteristics as a pulpwood source, the largest individuals of aspen in a given region are likely to be triploids, as is the case for the largest recorded aspen in Wisconsin (Einspahr *et al.* 1963) and in Riding Mountain National Park, Manitoba (W.J. Ball, pers. comm., Canadian Forestry Service, Winnipeg, Man., 1988).

15.4 Suggested Follow-up

Revel *et al.* (1986) have already suggested that the first boreal hardwood demonstration forest in the Dawson Creek area should include, not only examples of management practices in resident clones, but also intensive management of aspen or poplar hybrids and experimentation with banks of superior clones. Such demonstration areas cannot be established without substantial cost and commitment of annual budgets for maintenance and data collection. Thus, such demonstration areas are not likely to be established only for gene conservation reasons. However, if any presently known clones are suspected to be triploid, because of their exceptionally vigorous growth or large leaf size or large stem size, their locations should be recorded and given special protection, not only for gene conservation but also as sites for potential experimental and demonstration areas.

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APPENDIX 1

Working Group, Boreal Hardwood Research and Development Meeting, Prince George, 22 October 1987

NAME	AFFILIATION
Henry Benskin, Chairperson	Ministry of Forests, Victoria
Mike Carlson	Ministry of Forests, Vernon
Craig Delong	Ministry of Forests, Prince George
Les Herring	Ministry of Forests, Prince George
Barry Jaquish	Ministry of Forests, Vernon
Wayne Johnstone	Ministry of Forests, Vernon
Dick Nakatsu	Ministry of Forests, Prince George
Michael C. Pedersen	Ministry of Forests, Fort Nelson
Diane F. Renaud	Ministry of Forests, Fort St. John
John Revel	Ministry of Forests, Prince George
Wayne Thorp	Louisiana-Pacific Panel Products Ltd., Dawson Creek
Bill Williams	Ministry of Forests, Prince George
Cal Wilson	Ministry of Forests, Dawson Creek